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EVALUATION OF CKU-5/A EJECTION SEAT CATAPULTS UNDER VARIED ACCELERATION LEVELS

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Peter A. Lurker

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Post accident investigations of high performance aircraft, such as the F-16 led to the concern about the performance of the ACES II ejection seat catapult (CKU-5/A) loaded by an impressed acceleration. In response to this concern eight catapults were tested using a horizontal deceleration facility in cooperation with the F-16 System Program Office, the Life Support System Program Office, and the Naval Ordnance Station at Indian Head, Maryland. The objective of the tests was to evaluate the performance of the ACES II CKU-5/A catapult operating at impressed acceleration levels of 0, 3.5, and 7 G in the +Z axis. Analysis of the test results indicates that, although the velocity at separation was not significantly affected, significant delays in time to first motion and time to catapult strip-off occurred. Furthermore, critically high accelerations will be imparted to the ejection seat and crewmember. The Dynamic Response Index modeling technique was used to estimate the probability of injury from the catapult acceleration data. The probability of spinal injury increases from less than 1% at the 0-G level to greater than 99% at the 7-G level.

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PREFACE

This test and evaluation effort was accomplished under a memorandum of agreement with the F-16 System Program Office and the Life Support System Program Office. The project engineer for the F-16 System Program Office was Mr Michael Pudlowski. 1Lt Lisa Scoggins was the program manager and 1Lt Kit Boyd was the project engineer for the Life Support System Program Office.

The test program was planned and conducted by members of the Crew Protection Branch, Biodynamics and Bioengineering Division of the Armstrong Laboratory (AL/BBP). This report describes the results of tests to evaluate the performance of CKU-5/A ejection seat catapults operated under varied acceleration conditions.

The authors are grateful to Mr Thomas Ilkka of the Naval Ordnance Station, Indian Head, Maryland for his technical consultation during the planning and execution of the test program. The authors are also very grateful for the support provided by personnel of the Crew Protection Branch and the Technical Photographic Division of the 4950th Test Wing.

The test facilities, data collection, and data processing equipment were operated by the Scientific Services Division of DynCorp under Air Force contract number F33615-86-C-0531. Mr Marshall Miller was the engineering supervisor. The outstanding support of Mr Robert Flannery, Mr Steven Mosher, and Mr Ronald Riddle deserves special recognition.

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INTRODUCTION

Background

The flight characteristics of high-performance aircraft such as the F-15 and F-16 make it inevitable that emergency escape will occur during high-acceleration maneuvers of the aircraft. Such maneuvers may be intended by the pilot or they may be unintentional such as those caused by failure of the aircraft flight-control system.

A reduction in the margin of stability is typically incorporated into the design of contemporary, high-performance aircraft. Margin of stability is defined as the relationship between the center of pressure acting on the aircraft and the center of gravity of the aircraft. A negative margin of stability (center of pressure forward of the center of gravity) aids in the maneuverability of the aircraft, but it has a penalty associated with it as well. With a negative margin of stability, full-time active control of the aircraft is required to maintain a stable, forward-flying attitude. If control of the aircraft is lost, the crew must escape, but high accelerations of the uncontrolled aircraft may adversely affect the performance of the escape system. The escape system may also be subjected to high accelerations when ejection is initiated while the aircraft is in a dive-recovery maneuver to avoid ground impact.

Ejection of a seat and its occupant under high acceleration applied in the longitudinal axis of a catapult presents several potential hazards. First, the catapult may not be able to overcome the force due to the masses of the seat and occupant and the impressed acceleration of the aircraft maneuver. In this case the seat will not be ejected and, if the catapult is not structurally adequate, the catapult may explode. Second, the acceleration may not be adequate to eject the seat from the aircraft. Third, the acceleration may be adequate to eject the seat and the occupant from the aircraft, but the velocity of the seat and occupant might not be adequate to clear the tail structure of the aircraft. Fourth, the propellant within the catapult might burn faster and produce higher pressures, and thereby generate higher seat and occupant acceleration that may injure the occupant.

Concern about the performance of ejection catapults under impressed acceleration is not new. In 1979, the Flight Dynamics Laboratory sponsored a test program to investigate the performance of the Talley Industries 2400 series catapult. The test program was conducted by the Armstrong Laboratory (AL). During this program 14 catapults were tested, 7 at zero G, and seven at 7 G. The results of these tests showed a significant delay in the time to first motion of the seat after initiation of the catapult. These delays ranged from 15 to 25 msec at zero G to 70 to 85 msec at 7 G. Large increases of the catapult acceleration were also observed. The measured peak acceleration during the 7-G tests was generally the sum of the impressed acceleration and the acceleration produced at the zero-G condition.

In recent years several aircraft accidents have occurred where the ejection of ACES II seats and their occupants may have been delayed or perhaps stopped by high aircraft acceleration. Unfortunately, the results of the earlier tests of the Talley 2400 series catapult cannot be directly used to

analyze the performance of the ACES II seat. The ACES II seat catapult, the CKU-5/A, uses a different propellant, has a smaller piston diameter, and operates at a higher pressure. Therefore, the performance of the CKU-5/A can only be roughly estimated on the basis of the results of the tests with the Talley 2400 series catapult.

A mathematical model of the Talley 2400 series catapult was developed by Higgins (1982) at the USAF Academy to compute the acceleration produced by the catapult. The model was developed using the data from the tests conducted at AL. Good agreement was achieved between the acceleration-time profiles computed using the model and the test results. However, physical differences between the Talley 2400 series catapult and the ACES II catapult, such as the propellant type and the operating pressures, and assumptions made about specific model parameters preclude the use of the model to predict the performance of the ACES II catapult with any degree of confidence. For example, the propellant used in the CKU-5/A catapult has been tested to determine its burn rate at pressures up to 7500 psi. However, the CKU-5/A operates at a pressure of approximately 6000 psi under a zero-G initial condition and may produce pressures in excess of 15,000 psi above an impressed acceleration of 7 G.

In order to provide accurate data on the performance of the CKU-5/A catapult, the Life Support System Program Office and the F-16 System Program Office of the Aeronautical Systems Division requested that the Naval Ordnance Station (NOS), Indian Head, Maryland and the AL conduct tests. A test program was jointly planned by the system program offices, the NOS, and the AL. The NOS was tasked to inspect 50 CKU-5/A catapult tubes and choose ten, five of minimal internal mechanical clearance and five of maximum clearance, and assemble them without the rocket motor propellant. The first two catapults, one of minimal clearance and one of maximum clearance, were tested at the NOS to determine the structural strength of the catapults by performing "lock-shut" tests, that is, tests where the catapult was constrained to prevent axial motion. After determining that the catapults would not explode, the remaining catapults were delivered to the AL for testing. AL then tested the eight catapults using the Horizontal Deceleration Facility.

Critical Issues

Based on the aforementioned concerns about the performance of the CKU-5/A catapult, the following critical issues were defined and addressed in the AL test program.

1. Will the CKU-5/A catapult operate under high impressed acceleration? The catapult may not develop adequate force to propel the ejection seat up the rails.

2. How does the impressed acceleration affect the performance of the CKU-5/A catapult? Will the ejection velocity be reduced? Will the seat acceleration be decreased or increased? Will the times to first seat motion and at catapult strip-off be increased or reduced?

3. Does the mechanical clearance between the inner and outer tubes of the CKU-5/A catapult influence the catapult performance? Will tight clearances create significant additional frictional forces or loose clearances create leakages degrading the performance of the catapult?

4. How will the potential for spinal injury be altered when the CKU/5-A catapult is operating under varied acceleration levels?

Test Objectives

To evaluate the critical issues the following objectives were established:

1. To measure the acceleration, velocity, and displacement of an ejected sled as it is propelled by the CKU-5/A ejection catapult operating under varied acceleration conditions. These measurements are to be made in the axis parallel to the longitudinal axes of the test track and the catapult.

2. To measure the gas pressure within the CKU-5/A catapult and the forces at the seat mount and the airframe-mount ends of the catapult while the catapult is operating under varied acceleration conditions.

3. To compare the differences in measured forces and gas pressures when CKU-5/A catapults of different internal clearance dimensions are tested under otherwise identical test conditions. The clearance between the inner and outer tubes of the catapult is to be controlled by pre-test selection.

4. To measure the z-axis acceleration-time history of the payload sled and estimate the probability of spinal injury by using the Dynamic Response Index technique.

5. To provide data required to develop and verify a mathematical model of the performance of the CKU-5/A catapult.

METHODS AND EQUIPMENT

Technical Approach

An experimental design was developed to evaluate the performance of the catapult operating under impressed acceleration. The acceleration conditions that were used in this test program were selected to approximate the +Gz acceleration of a seat and its occupant experienced during a high-performance maneuver by the aircraft, such as recovering from a dive. Although high-performance aircraft, such as the F-16, may incur +Gz acceleration up to 9 G, the highest acceleration condition was restricted by the test facility. The pneumatic brake system, which was used to produce the acceleration profile, has a pressure limit of 700 psi. A brake pressure of 700 psi produces an acceleration amplitude of approximately 7 G.

Three levels of impressed acceleration were chosen for this test program. The first level, zero G, was used to verify the experimental setup by comparison with previous tests of the CKU-5/A catapult, which had been conducted by the NOS (Petterson, 1978). The second level was 7 G. The third level, 3.5 G, was chosen as an additional data point to evaluate the linearity of the catapult performance and to use in the development of a mathematical model of the catapult.

Eight catapults were tested. They were selected from two lots. Lot one contained four catapults of maximum allowable clearance between the inner tube and the outer tube of the catapult. Lot two contained four catapults of minimum allowable clearance between the inner tube and the outer tube. The catapults selected from each lot were tested under the acceleration conditions shown in Table 1.

TABLE 1. CATAPULT TEST MATRIX

ACCELERATION LEVEL (G)	0	3.5	7
MINIMUM CLEARANCE	A	C	G
MAXIMUM CLEARANCE	B	D	H

The controlled variables for this test program were the clearance dimensions of the catapult tubes, the acceleration of the carrier and payload sleds at time of catapult initiation, and the velocity of the payload and carrier sleds at time of catapult initiation. The weights of the carrier sled, payload sled, and the pre-ignition temperature of the catapult were identical for all tests.

The measured variables were the catapult internal pressure, forces at each end of the catapult, catapult extension distance, acceleration of the carrier and payload sleds, velocities of the carrier and payload sleds, and catapult-ignition time. Calculated parameters included catapult-extension rate and Dynamic Response Index (MIL-S-9479B). Catapult strip-off time, i.e., the time where the inner catapult tube and outer catapult tube separate, was determined from the catapult extension-time history, and the strip-off time was used to determine the corresponding strip-off velocity.

In order to evaluate the statistical significance of the measurements, the following null hypotheses were developed:

1. The level of the impressed acceleration will not affect the CKU-5/A catapult performance parameters.

2. The minimum and maximum mechanical clearances between the inner tube and the outer tube of the catapult will not affect the CKU-5/A performance parameters.

3. The magnitude of the impressed acceleration will not affect the probability of spinal injury estimated by the Dynamic Response Index.

The null hypotheses were evaluated using the Student's t test for matched pairs (Volk, 1969). The confidence level that was selected for rejection of the null hypothesis was 90 percent for a two-tailed test.

Test Item

The CKU-5/A catapult evaluated during this test program is a two-stage propulsion device. The first stage accelerates the seat and its occupant up rails mounted to the aircraft. The first stage is powered by a pyrotechnic cartridge housed inside the inner booster tube of the catapult. When the cartridge is initiated by gas pressure delivered through the breech of the catapult, high-pressure gas generated by the catapult propellant releases the lock mechanism between the inner booster tube and the outer launcher tube. The high-pressure gas forces the two tubes apart along their longitudinal axis until separation (strip-off) occurs. A sectional view showing the components of the catapult is in Figure 1.

Just prior to separation, the second stage of the ejection catapult is initiated. The second stage consists of a rocket motor that provides additional acceleration of the seat and its occupant after separation from the aircraft. The rocket propellant, which is contained in the outer launcher tube assembly, is ignited by the hot gases generated during the operation of the first stage. The high-pressure gas from the burning rocket propellant is directed through the rocket nozzle located at the lower end of the launcher tube assembly. The rocket thrust vector acts approximately through the center of gravity of the seat and its occupant to propel them to a height suitable for a safe recovery by parachute.

The second stage of the catapult was not evaluated during this test program. During assembly of the two lots of catapults by the NOS, the rocket propellant was not put in the catapults used in this test program.

Gas pressure from an M-53 pyrotechnic initiator was used to ignite the propellant within the catapult. The M-53 initiator was activated by an Holex™ electrical igniter cartridge model 6104. The electrical igniter was activated by a current transmitted from the facility control system.

Horizontal Deceleration Facility

The AL Horizontal Deceleration (HD), shown in Figure 2 (taken from Appendix A, page A-16), was used to test the catapults. The facility consists of a launch system, a track, an impact sled, a hydraulic decelerator and a

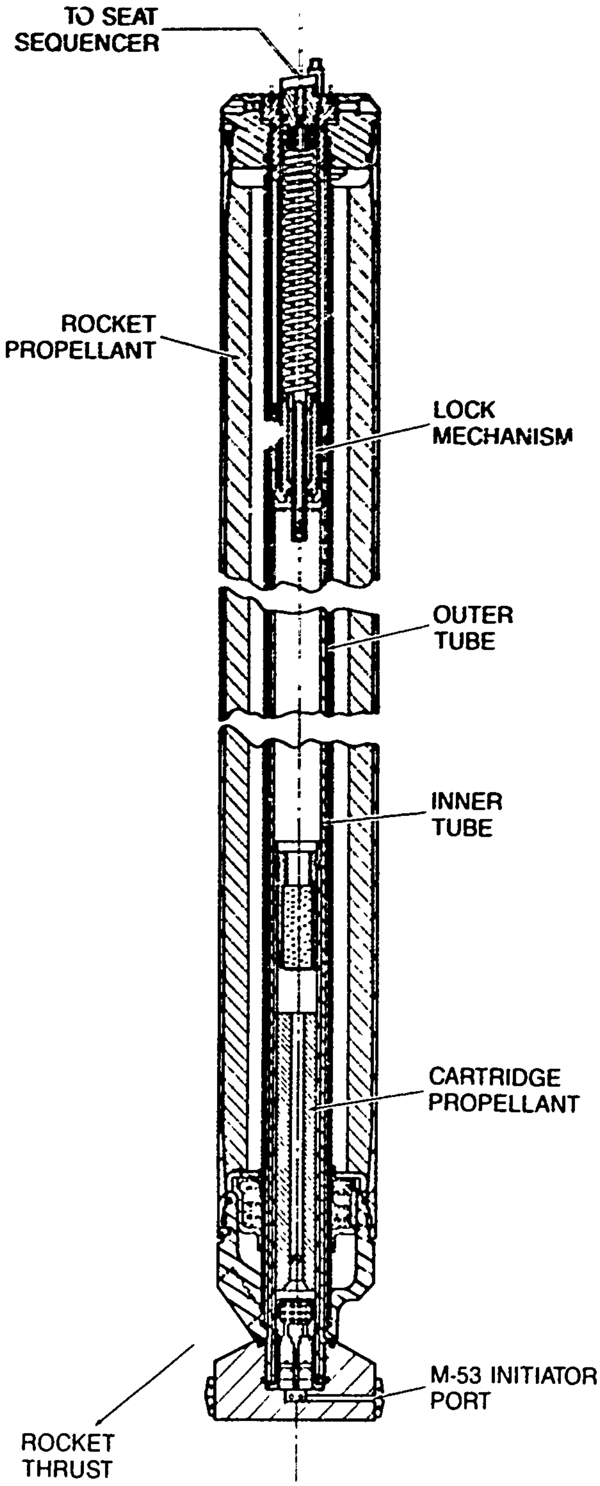

FIGURE 1. CROSS SECTIONAL VIEW OF CKU-5/A CATAPULT

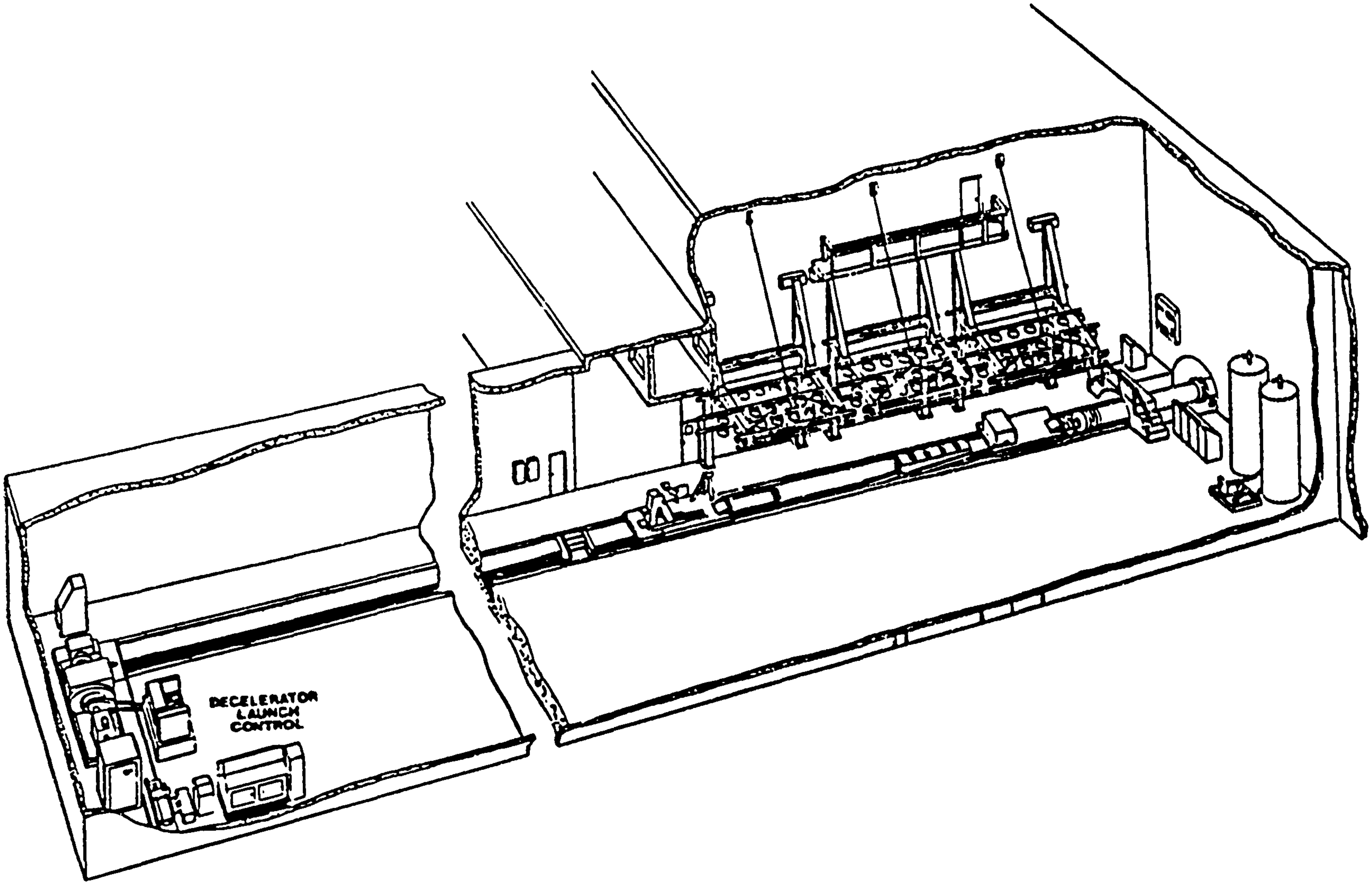

FIGURE 2. AL/BBP HORIZONTAL DECELERATION TEST FACILITY

safety and control system. The launch system, which is used to accelerate the impact sled, is shown in Figure 3 (taken from Appendix A, page A-17). Prior to initiation of testing, energy is stored in a flywheel that is driven by an electric motor. During a launch, the flywheel is coupled to a reel by an electronically controlled hydraulic clutch. Fabric tape, attached to the reel and a shuttle sled, is wound onto the reel to accelerate the shuttle sled, which pushes the impact sled toward the hydraulic decelerator. The acceleration phase of the launch occurs for a distance of approximately 75 ft. The impact sled then separates from the shuttle sled and coasts approximately 135 ft to the impact area.

The principal component of the hydraulic decelerator, shown in Figure 4 (taken from Appendix A, page A-18), is a horizontal cylinder bored within a series of steel blocks. The cylinder blocks are mounted within a water containment enclosure. At the point of impact, a 5-ft long piston attached to the impact sled punctures a polyethylene retaining membrane and forces the water within the cylinder through the orifices in the cylinder wall. In Figure 4, the top of the water enclosure has been removed to show the positions of the orifice plugs that surround the cylinder block. The deceleration profile is controlled by varying the diameter of the orifices.

The hydraulic decelerator was not used to produce the acceleration conditions for the CKU-5/A catapult tests. It was used as a backup to stop the sleds in the event of failure of the impact sled pneumatic brakes. The pneumatic brake system of the impact sled was used to produce the acceleration conditions.

Figure 5 (taken from Appendix A, page A-20) shows the test configuration of the impact sled (referred to as the carrier sled) and the payload sled. The payload sled was designed to fit onto the track rails of the horizontal decelerator. It was connected to the carrier sled via the catapult, which was enclosed inside the catapult container. The weight of the payload sled was 345 lb. Thirty pounds of ballast weight was added to the sled to match the weight of an ACES II ejection seat with a 180 lb occupant (375 lb).

During the launch phase the payload sled was towed behind the carrier sled through the connection provided by the catapult. At midtrack the pneumatic brakes of the carrier sled were activated by switches, which were triggered by ramps positioned beside the track. The carrier sled brake system was powered by nitrogen gas stored in pressure cylinders on the carrier sled. The acceleration level was a function of the amount of pressure stored in the gas cylinders. When the desired acceleration level was achieved the catapult was initiated.

During the deceleration phase the catapult experiences compression loading. Figure 6 shows the experimental setup for the 3.5- and 7-G conditions. For the zero-G condition the payload sled was propelled from the carrier sled by the catapult while the carrier sled was locked on the rails of the track by the brake system. Figure 7 shows the setup for the static test condition.

All tests accomplished using the Horizontal Deceleration Facility are initiated and controlled by a safety and control system. This system monitors the status of critical launch system components, sled velocity, the data acquisition systems, and test area security. The system also

FIGURE 3. LAUNCH SYSTEM

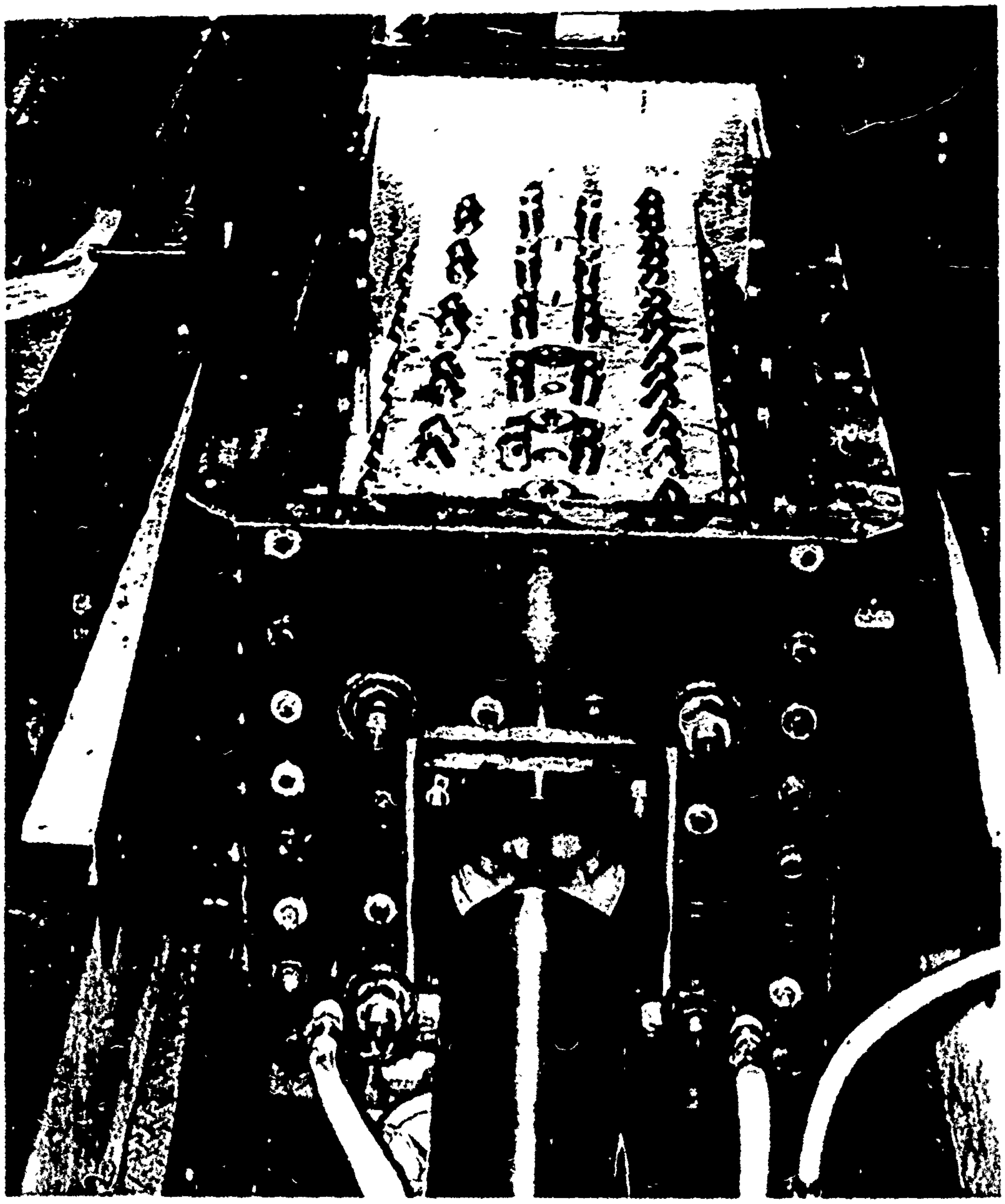

FIGURE 4. HYDRAULIC DECELERATOR

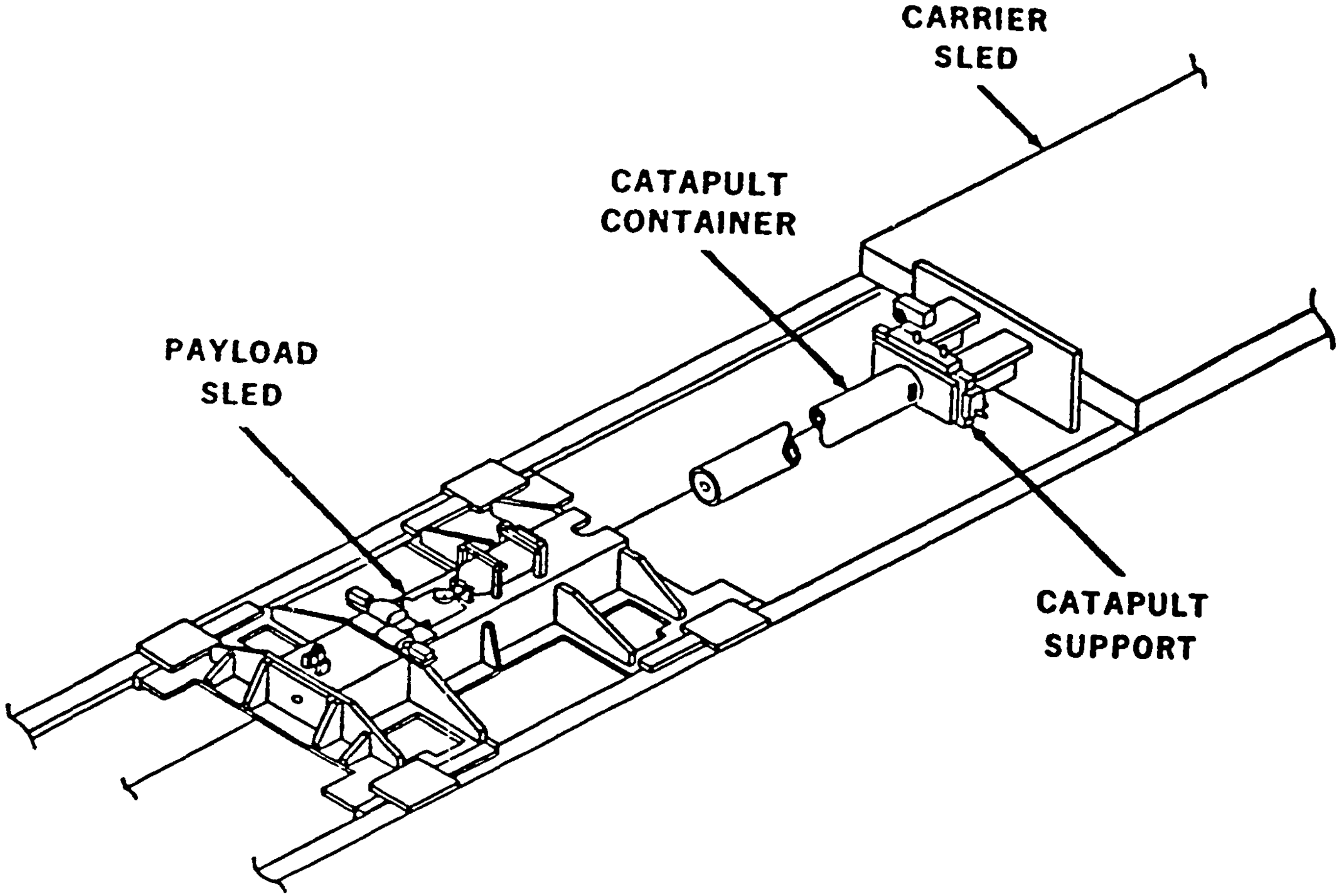

FIGURE 5: TEST CONFIGURATION OF THE IMPACT AND PAYLOAD SLED

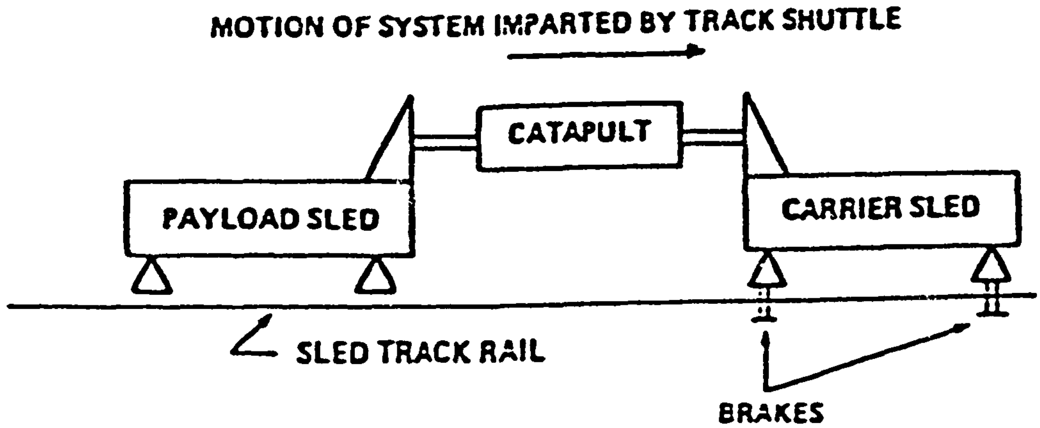

FIGURE 6. SCHEMATIC OF TEST SET-UP FOR DYNAMIC TEST

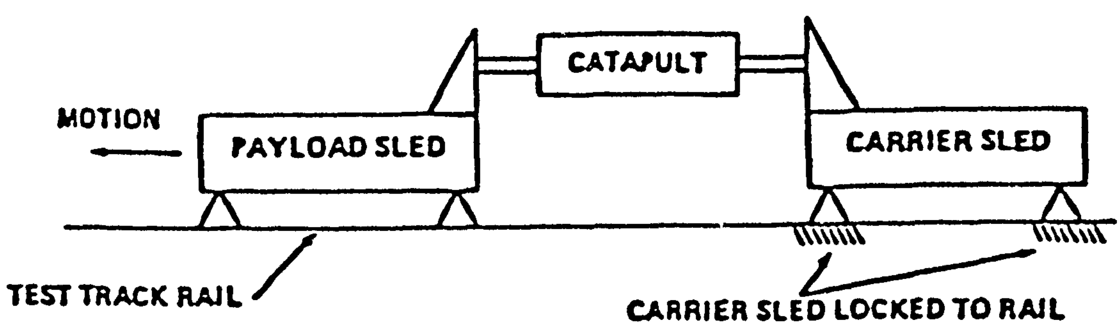

FIGURE 7. SCHEMATIC OF TEST SET-UP FOR STATIC TEST

provides automatic test abort if the equipment status is unacceptable or if the safety officer or operator initiates an abort sequence.

Acceleration Profiles

Previous testing experience with the CKU-5/A catapult has been under the zero-G acceleration condition (Petterson, 1978). At this test condition, the time required for catapult separation was approximately 175 msec and the peak acceleration was approximately 12 G. The only tests of ejection seat catapults in an acceleration environment has been with the Talley Industries 2400 series catapult (Boedeker, 1979, Higgins, 1982). During these tests, delays of up to 70 msec were encountered from the time of initiation of the catapult to the time of first motion. Therefore, an acceleration duration of at least 250 msec was chosen for testing the CKU-5/A catapult.

Figures 8 and 9 show carrier sled acceleration data for the 3.5- and 7-G test conditions. The acceleration of the carrier sled was not constant for the duration of the event due to the variations of frictional force between the brake pads and track rails and, to a greater degree, by the reactive forces from the operation of the catapult. The coefficient of friction between the pads and rails increased due to temperature increase in the pads and possibly from contamination buildup on the brake pads.

The catapult provided the force necessary to propel the payload sled from the carrier sled. On the basis of Newtonian physics, the force applied to the payload sled is reacted to the carrier sled. Since the reactive force from the catapult is in the opposite direction to the frictional forces from the brakes, the deceleration of the carrier sled is reduced. The change in acceleration is a function of the masses of the two sleds, friction forces, and the internal pressures generated by the burning propellant within the catapult.

Electronic Instrumentation

Electronic data collected during the tests included carrier and payload-sled acceleration, carrier and payload-sled velocity, loads at each end of the catapult, catapult extension, internal catapult gas pressure and igniter initiation time. Detailed descriptions of the instrumentation, electronic data processing equipment, mounting procedures, and calibration techniques are provided within Appendix A. The following information summarizes the electronic instrumentation that was used to acquire the test data.

Acceleration of the two sleds was measured using miniature, piezoresistive accelerometers mounted to the under-structure of the carrier sled and to the top surface of the payload sled. Velocities of the two sleds were measured using small tachometers driven by friction wheels riding on the rail of the HD track.

Catapult forces acting on the two sleds were measured using load cells. The extension of the catapult was measured using a string potentiometer mounted on the carrier sled. The other end of the string was tethered to the payload sled. Catapult pressure was measured using a piezoresistive pressure transducer attached to the pressure port at the seat-mount end of the catapult.

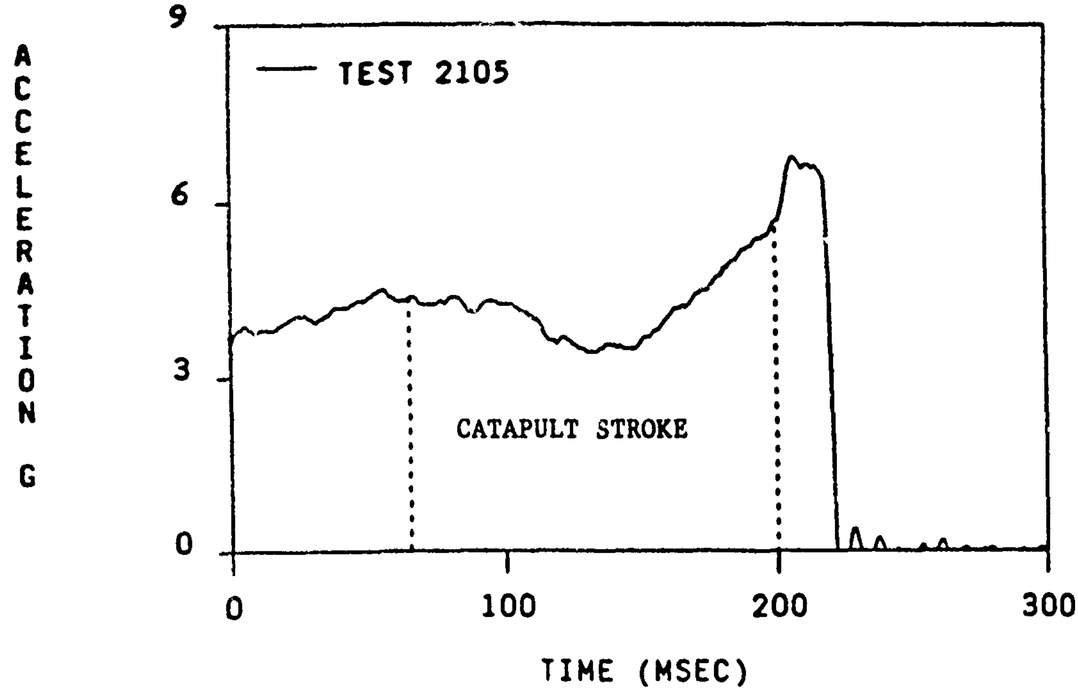

FIGURE 8. CARRIER SLED ACCELERATION VERSUS TIME, AL TEST 2105

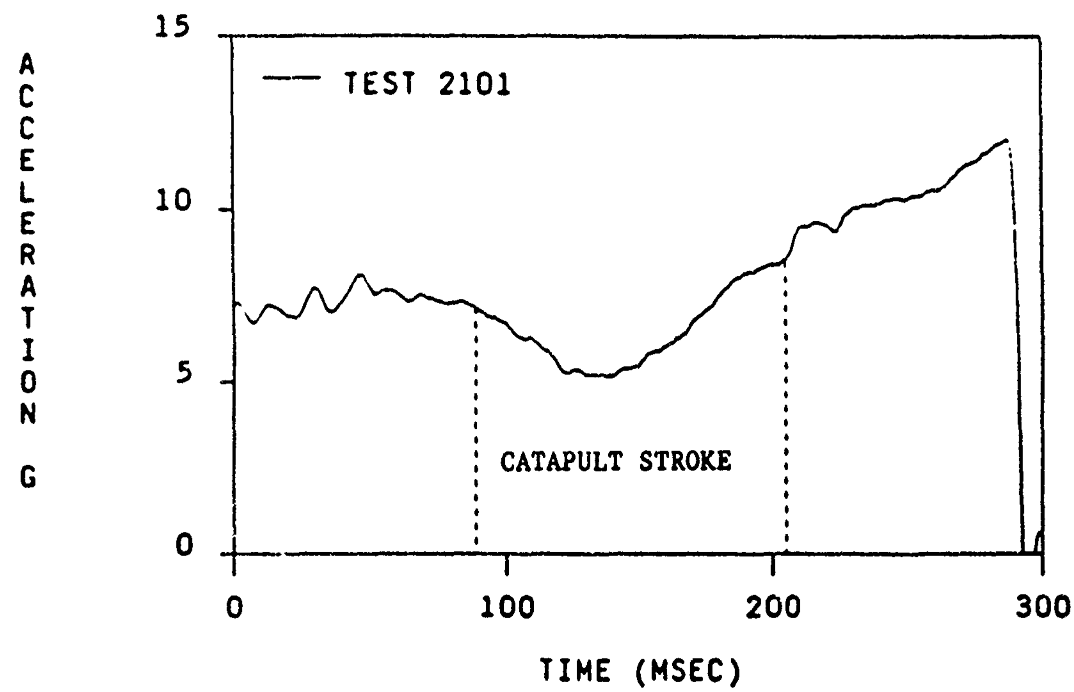

FIGURE 9. CARRIER SLED ACCELERATION VERSUS TIME, AL TEST 2101

Data Acquisition and Recording

All electronic data were recorded as a function of time on an analog data acquisition system. Data were later played back through the Automatic Data Acquisition and Control (ADAC) system and digitized at a rate of 1000 samples per second. For this test program nine channels of test data were recorded plus three channels of facility and equipment monitoring data.

The ADAC system is a 48-channel data acquisition system with filtering, amplification, and encoding of all 48 data channels into a digital format (pulse code modulation) for transmission through an umbilical cable to a word formatter. The word formatter reformats the serial data, which are then routed to a computer for storage, analysis, and control. For details on these systems, see Appendix A.

Photogrammetric Instumentation

The movements of the payload and carrier sleds were recorded by photographing the motion of fiducial markers attached to the two sleds. Two 16-mm cameras were used. The cameras were operated at a speed of 500 frames per second with a shutter opening of 140 degrees. A LOCAM camera, model 164-SAC, with a 9-mm lens was mounted on a fixed structure adjacent to the HD track to record the motion of both sleds with respect to the laboratory reference frame. A LOCAM camera, model 50-0002, with a 10-mm lens was mounted on the left front corner of the carrier sled and provided an oblique view of the two sleds before, during, and after the event.

Timing-reference marks were recorded on the 16-mm film once every 0.01 sec. These reference marks were synchronized with the electronic instrumentation.

Ten fiducial markers, which were attached to the two sleds, consisted of 1.25-inch diameter black spots printed on 2.00-inch diameter white targets. The location of the markers were the same for all the tests. More complete descriptions of the fiducial marker locations as well as the photometric instrumentation system are provided in Appendix A.

A video camera was also used to document the tests. This camera and the recorder used with it are capable of recording motion at a rate of 120 frames per second with an effective shutter speed of 10 microseconds or less. Use of this system allowed the investigators to evaluate the dynamic motion of the two sleds immediately after the tests. This system is also described in Appendix A.

Engineering Safety

An independent safety review was accomplished by the AL Technical Safety Committee. The safety committee surveyed the test facility to evaluate the operational procedures, maintenance, potential failure modes, failure risks, operational history, and demonstrated reliability in accordance with the AL Regulation 127-1 (1976).

Electronic Data Reduction

Data from each test were reduced in a standardized format. Examples of reduced electronic data may be reviewed in Appendix B. Computed summaries

provide relevant maxima and minima from the recorded signals. The maxima listed for the carrier sled acceleration are the acceleration of the carrier sled at the time of maximum payload sled acceleration. Listed also are relevant times, computed catapult separation rate, and computed Dynamic Response Index values. Scaled plots of the recorded signals and computed values are also presented.

Photogrammetric Data Processing

The linear motion in the z axis of the carrier sled and payload sled was derived by an analysis of the 16-mm high-speed films. The analysis method for the photogrammetric data reduction used the films from the stationary camera mounted adjacent to the HD track. The fiducial markers on the two sleds were electronically tracked with a PDS Model 200 Photo Digitizing System (PDS), which includes an Automatic Film Reader (AFR), an electronic scanning camera, and a DGC NOVA 3/12 computer.

The AFR is manually initialized by designating the targets of interest with a cursor in the first frame of data. Targets on subsequent frames are automatically scanned, acquired, and identified, and the x and z coordinates of the target are recorded. Up to seven targets within one film frame could be automatically scanned at a rate of 1/2 frame per second. The AFR also extracted digital timing information from the timing marks on the films.

The frame-by-frame digitized position coordinates of the fiducials and timing data were processed by the NOVA computer and stored on magnetic tape. These digital data were used by a computer program that computed and plotted the actual displacements, velocities, and accelerations of the fiducials of interest.

The films from all the tests were digitized and the plots of displacement and velocity of selected targets are presented in Appendix C, except test 2105. The film for test 2105 could not be digitized because the fiducials were out of the field of view of the camera during the event.

Test Procedures

The catapult tests were accomplished under the direction of a qualified and experienced test conductor. The test conductor assured that the equipment, facility, and pyrotechnic devices were properly setup prior to each test.

At the beginning of each day of testing, personnel of the 4950th Test Wing, Egress Shop, delivered two catapults (one from each lot) to the test facility, and remained at the site to assist in the handling, installation, removal, and disposition of the pyrotechnic devices. The temperature of the catapults was allowed to stabilize for two hours at the test site prior to the test. The laboratory temperature was controlled to 70 ± 2 degrees Fahrenheit.

The first two tests were accomplished with one catapult from each of the two lots at the zero-G conditions (Cells A and B). During these two tests the payload sled was propelled from the carrier sled by the catapult while the carrier sled was locked on the rails of the track.

The high-speed motion picture cameras were loaded and mounted on the sled and adjacent to the test track. After all instrumentation had been checked and readied, and the brakes pressurized to lock the sled to the track, all personnel except the pyrotechnic technicians, safety officer, and test conductor left the test site. The pyrotechnic technicians then inserted and mounted the catapult to the loadcell located on the carrier sled. The payload sled was then connected to the other end of the catapult via a loadcell. After connection of the pyrotechnic initiator, a safety check was performed and all personnel left the test site. The test was then initiated from the instrumentation room by means of an electrical signal. After completion of the test, the pyrotechnic technicians removed the catapult from the fixture and returned it to their facility for inspection by the NOS.

During the dynamic tests (cells C, D, G, and H), the sled was positioned at the launching system. After installation of the catapult by the pyrotechnic technicians, all personnel except the horizontal decelerator operator and the safety officer left the test site. They remained to attach the sleds to the launching system and initiate the test. At initiation by the operator, the sled/catapult assembly was propelled by the shuttle of the launch system along the track with the payload sled, which was towed behind the carrier sled. At midtrack, pneumatic brakes on the carrier sled were activated. When the preprogrammed acceleration level was achieved, the catapult was initiated. The post-test procedures for the dynamic test were the same as the post-test procedures for the static (zero-G) tests.

RESULTS

Armstrong Laboratory Test Data

The results of the eight tests are summarized in Tables 2, 3, and 4. Maximum and minimum values of each measurement recorded or computed as well as graphs of measured data for each test are presented in Appendix B.

A review of definitions is warranted to assist in the understanding of the parameters presented in Tables 2, 3, and 4. The event is defined as occurring between the time of initiation of the catapult to the time of separation of the catapult. The point of catapult separation, referred to as stri -off, is defined as occurring at 34.5 inches of stroke of the catapult, which is the definition used by the NOS. Strip-off distance was determined from the catapult extension measurement. Delay time to first motion is defined as the time from initiation of the catapult to the time at which a discernible displacement is first measured by catapult extension. The Dynamic Response Index is computed using the payload sled acceleration-time history as the input data. Strip-off velocity is a computed value defined as the difference between the payload-sled velocity and the carrier-sled velocity at the time of catapult separation.

The payload-sled acceleration increased dramatically as the impressed acceleration level increased. The increase was much greater than the sum of the peak acceleration at zero G and the impressed acceleration as was found during testing of the Talley 2400 series catapult. The time to peak payload acceleration decreased as the impressed acceleration level was increased.

The strip-off velocity demonstrated no trend as a function of the impressed acceleration level other than a larger deviation from the mean at the highest acceleration level. Time of strip-off and delay time to first motion both exhibited an increase as a function of the impressed acceleration level. The measured pressure and forces, which are proportional to the acceleration of the payload sled, increased as the acceleration level increased.

Comparison with Naval Ordnance Station Tests

The data from the tests of the CKU-5/A catapult conducted by the NOS (Petterson, 1978) were used in the statistical evaluation of the null hypotheses for this program. Two catapults from the test lot were tested by the NOS using their test facility. The data were provided to the AL for comparison with the two tests conducted at the zero-G level (cells A & B). Plots of the measured accelerations and forces are presented in Figures 10 thru 13. The difference between the NOS and AL results were found to be no greater than the differences between the catapults tested at the NOS by Petterson. Table 5 summarizes the measured data from the four tests. The time data points shown in Table 5 for the two AL tests were adjusted to allow for the differences in experimental setup between AL and NOS. Therefore, the values will not be the same as those shown in Table 2.

TABLE 2. SUMMARY OF RESULTS OF CKU-5/A CATAPULT TEST CELLS A AND B

TEST NUMBER	2099	2100
CATAPULT NUMBER	10	2
CATAPULT TOLERANCE	MIN	MAX
ACCELERATION ENVIRONMENT (G)	0	0
AVERAGE CARRIER SLED ACCELERATION DURING THE EVENT (G)	0	0
MAXIMUM CARRIER SLED ACCELERATION DURING EVENT (G)	0	0
MINIMUM CARRIER SLED ACCELERATION DURING EVENT (G)	0	0
PEAK PAYLOAD ACCELERATION (G)	11.6	12.0
TIME OF PEAK PAYLOAD ACCELERATION (MSEC)	171	169
STRIP-OFF VELOCITY (FPS)	40.7	41.7
STRIP-OFF TIME (MSEC)	185	185
DELAY TIME TO FIRST MOTION (MSEC)	44	41
PEAK CATAPULT PRESSURES (PSI)	6009	6119
PEAK PAYLOAD FORCE (LB)	4543	4702
PEAK CARRIER FORCE (LB)	4722	4947
DYNAMIC RESPONSE INDEX	11.6	12.1

TABLE 3. SUMMARY OF RESULTS OF CKU-5/A CATAPULT TEST CELLS G AND H

TEST NUMBER	2101	2102	2103	2104
CATAPULT NUMBER	9	3	8	4
CATAPULT TOLERANCE	MIN	MAX	MIN	MAX
ACCELERATION ENVIRONMENT (G)	7	7	7	7
AVERAGE CARRIER SLED ACCELERATION DURING THE EVENT (G)	6.9	7.3	7.1	7.3
MAXIMUM CARRIER SLED ACCELERATION DURING EVENT (G)	9.0	9.8	9.2	9.4
MINIMUM CARRIER SLED ACCELERATION DURING EVENT (G)	5.2	5.3	5.3	5.8
PEAK PAYLOAD ACCELERATION (G)	28.5	29.3	28.5	28.2
TIME OF PEAK PAYLOAD ACCELERATION (MSEC)	141	141	138	143
STRIP-OFF VELOCITY (FPS)	40.8	36.0	40.0	37.8
STRIP-OFF TIME (MSEC)	208	212	206	213
DELAY TIME TO FIRST MOTION (MSEC)	92	92	95	97
PEAK CATAPULT PRESSURES (PSI)	13,802	14,351	13,692	13,391
PEAK PAYLOAD FORCE (LB)	10,989	11,042	11,144	11,144
PEAK CARRIER FORCE (LB)	11,340	11,504	11,777	11,7[illegible]
DYNAMIC RESPONSE INDEX	30.9	30.6	30.6	30.3

TABLE 4. SUMMARY OF RESULTS OF CKU-5/A CATAPULT TEST CELLS C AND D

TEST NUMBER	2105	2106
CATAPULT NUMBER	7	5
CATAPULT TOLERANCE	MIN	MAX
ACCELERATION ENVIRONMENT (G)	3.5	3.5
AVERAGE CARRIER SLED ACCELERATION DURING THE EVENT (G)	4.2	4.0
MAXIMUM CARRIER SLED ACCELERATION DURING EVENT (G)	6.1	5.7
MINIMUM CARRIER SLED ACCELERATION DURING EVENT (G)	3.5	2.9
PEAK PAYLOAD ACCELERATION (G)	21.0	21.0
TIME OF PEAK PAYLOAD ACCELERATION (MSEC)	151	153
STRIP-OFF VELOCITY (FPS)	41.3	42.7
STRIP-CFF TIME (MSEC)	203	201
DELAY TIME TO FIRST MOTION (MSEC)	72	74
PEAK CATAPULT PRESSURES (PSI)	11,487	11,197
PEAK PAYLOAD FORCE (LB)	8244	9001
PEAK CARRIER FORCE (LB)	8552	9524
DYNAMIC RESPONSE INDEX	22.1	23.0

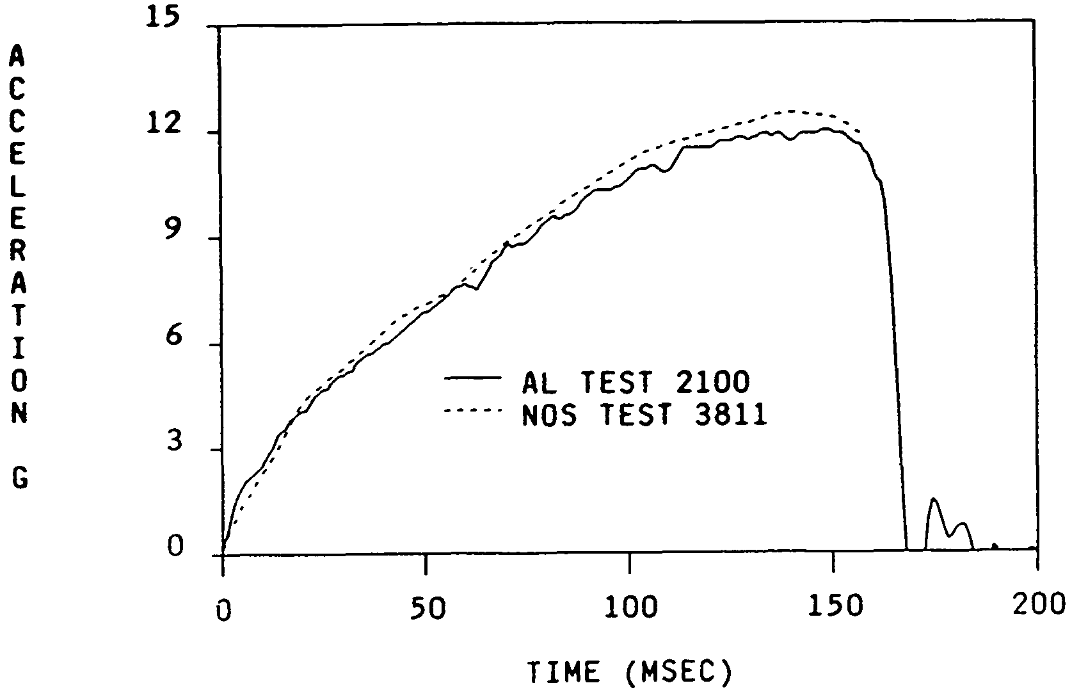

FIGURE 10. PAYLOAD SLED ACCELERATION VERSUS TIME, NOS TEST 3811 AND AL TEST 2100

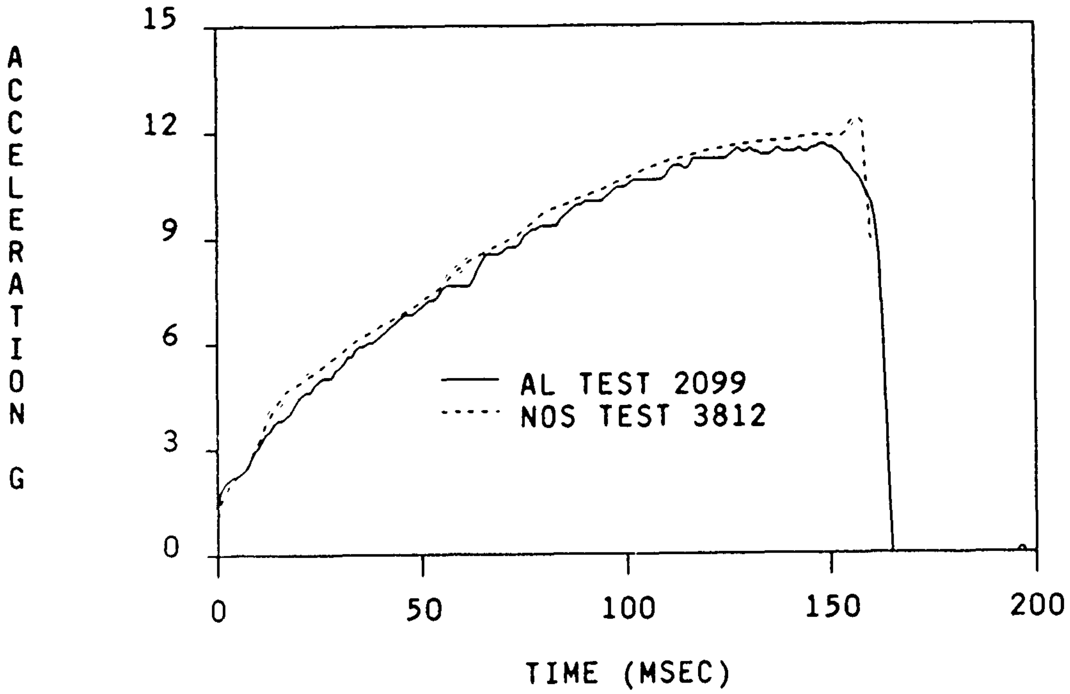

FIGURE 11. PAYLOAD SLED ACCELERATION VERSUS TIME, NOS TEST 3812 AND AL TEST 2099

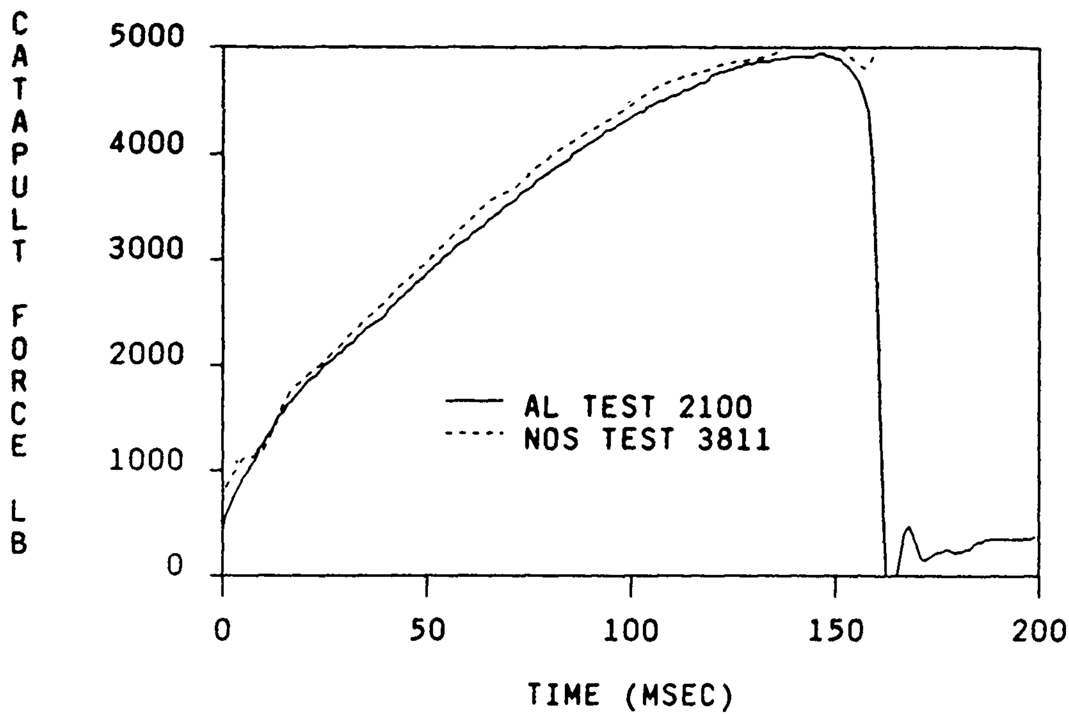

FIGURE 12. CATAPULT FORCE VERSUS TIME, NOS TEST 3811 AND AL TEST 2100

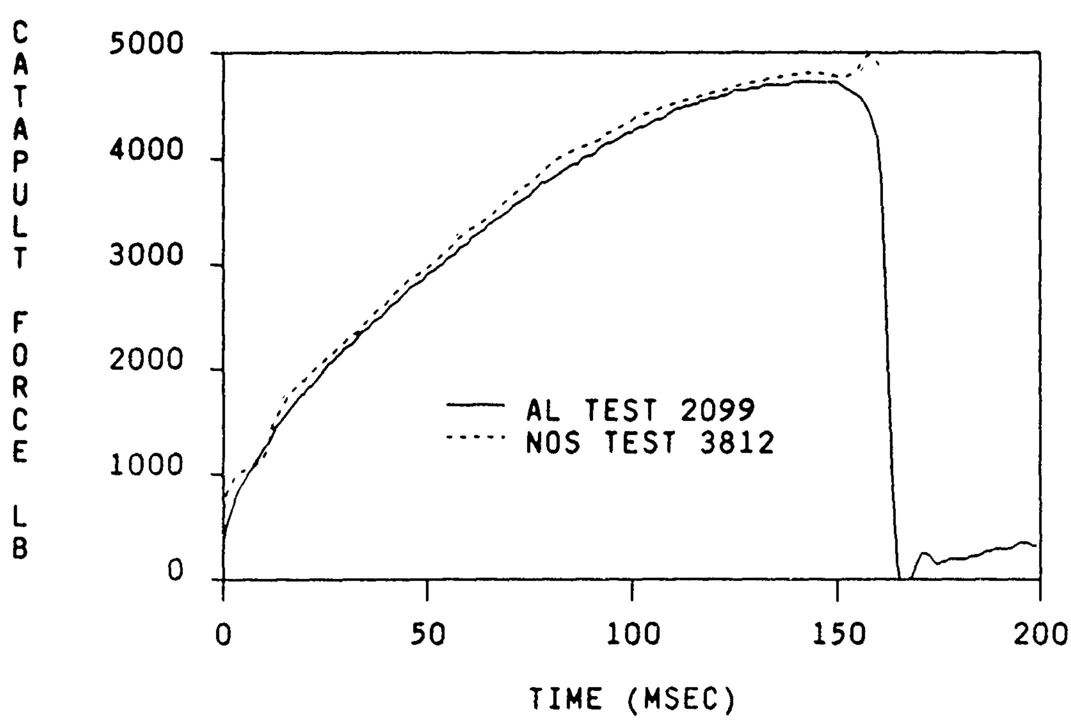

FIGURE 13. CATAPULT FORCE VERSUS TIME, NOS TEST 3812 AND AL TEST 2099

TABLE 5. COMPARISON OF AL AND NOS ZERO-G TEST RESULTS

PARAMETER	NOS		AL	
TEST NUMBER	3811	3812	2099	2100
CATAPULT TOLERANCE	UNKNOWN	UNKNOWN	MIN	MAX
PEAK PAYLOAD ACCELERATION (G)	12.2	11.7	11.6	12.0
TIME OF PEAK ACCELERATION (MSEC)	142	158	151	148
STRIP OFF VELOCITY (FPS)	44.8	43.3	40.7	41.7
STRIP OFF TIME (MSEC)	157	162	164	163
PEAK PRESSURE (PSI)	6524	6180	6009	6119
PEAK PAYLOAD FORCE (LB)	5020	4143	4543	4702
DYNAMIC RESPONSE INDEX	12.4	11.8	11.6	12.1

Effects of Acceleration Level

Two data samples were used to evaluate the first null hypothesis: Impressed acceleration will not affect the catapult performance parameters. One sample was composed of the results from all the tests conducted at the AL at the 3.5- and 7-G conditions, and the second sample was the results of the tests conducted at the NOS at the static (zero-G) condition. The data from the tests conducted at the AL are shown in Tables 2, 3, and 4 and the data from the tests conducted at the NOS are shown in Table 6.

Table 7 shows the computed t values and confidence level for rejection of null hypothesis foı the data evaluated for this statistical analysis.

The null hypothesis: Impressed acceleration will not affect the performance of the CKU-5/A catapult: it is rejected because the confidence level for rejection of the hypothesis for the data parameters evaluated is greater than 90%, which is the level chosen for rejection.

Mechanical Clearance Effects

Data collected from catapults with minimum inner-to-outer tube clearance were matched with data from tests of catapults with maximum inner-to-outer tube clearance. These matched pairs were used to evaluate the second null hypothesis: The mechanical clearance will not affect the performance of the catapult. For the matched pairs, cell A was matched with cell B, cell C with cell D, and cell G with cell H. The data points used in this evaluation were taken from Tables 2, 3, and 4.

Table 8 shows the computed t values and confidence level for rejection of the null hypothesis for the data evaluated for this statistical analysis.

TABLE 6. RESULTS FROM CKU-5/A TESTS CONDUCTED AT NOS

TEST	PEAK PAYLOAD ACCELERATION	STRIP-OFF VELOCITY	STRIP-OFF TIME	PEAK PRESSURE	DRI
3811	12.2	44.8	157	6524	12.4
3812	11.7	43.3	162	6180	11.8
4244	12.2	44.4	162	6055	12.0
4245	11.5	43.4	163	5943	11.3
4701	11.3	42.5	165	5616	11.3
4702	11.3	42.5	165	5364	11.0
4703	11.8	43.0	165	----	11.3
4704	12.0	43.5	165	5916	11.8
NOS	12.6	45.0	160	5866	12.4
NOS	12.3	44.3	165	5662	12.1

TABLE 7. STATISTICAL INFERENCE OF IMPRESSED ACCELERATION EFFECTS

PARAMETER	T VALUE	CONFIDENCE LEVEL FOR REJECTION
PEAK PAYLOAD ACCELERATION	3.56	99.9%
STRIP-OFF VELOCITY	2.87	99.6%
TIME TO STRIP-OFF	6.51	>99.9%
PEAK PRESSURE	3.51*	99.9%
DRI	3.57	99.9%

*NOTE: t value = 1.7 for 13 degrees of freedom

The null hypothesis that the minimum and maximum mechanical clearance between the catapult inner and outer tubes will not affect the performance of the CKU-5/A catapult is not rejected because the confidence level for rejection of the hypothesis is 90% or less, which is the level chosen for rejection for the data parameters evaluated.

TABLE 8. STATISTICAL INFERENCE OF MECHANICAL CLEARANCE EFFECTS

PARAMETER	t VALUE	CONFIDENCE LEVEL FOR REJECTION
PEAK PAYLOAD ACCELERATION	1.567	88.3%
TIME TO PEAK ACCELERATION	0.837	59.7%
STRIP-OFF VELOCITY	0.788	56.9%
TIME TO STRIP-OFF	1.116	73.5%
DELAY TIME TO FIRST MOTION	0.212	16.8%
PEAK PAYLOAD FORCE	1.386	83.4%
PEAK CARRIER FORCE	1.653	90.2%
PEAK CATAPULT PRESSURE	0.084	6.7%

Effects on Probability of Injury

The third null hypothesis: The magnitude of the impressed acceleration will not affect the probability of spinal injury, was evaluated using the Dynamic Response Index (DRI) technique. The payload sled acceleration data were used as the input function to the DRI model. The average DRI values for similar test conditions are presented in Table 9.

TABLE 9. PROBABILITY OF SPINAL INJURY

IMPRESSED ACCELERATION (G)	MEAN DRI	PROBABILITY OF INJURY (%)
0	12.0	<0.1
3.5	22.6	48
7	30.6	>99

The values in Table 9 clearly show that the probability of spinal injury increases in major increments when the impressed acceleration acting on the catapult is increased from 0 G to 7 G. The estimated probability of injury increased from less than one percent to greater than 99 percent. Therefore, the null hypothesis is rejected.

DISCUSSION

Implications of the Results

The concerns expressed as a result of several accident investigations have been that the performance of the catapult would be so degraded that the seat and its occupant would not be ejected from the aircraft, and/or that the operation of the catapult would be significantly delayed under high impressed acceleration. The test results show that the velocity at catapult strip-off is not significantly affected by impressed acceleration up to 7 G. This finding may not be true at higher impressed acceleration levels; there is evidence that the propellant was expended prior to catapult strip-off in both the 3.5- and 7-G tests. This is demonstrated by the earlier time to peak pressure and then rapid decrease in pressure that is shown in Figure 14 by comparison with the zero-G test results.

The apparent delays in the pressure-time response demonstrated in Figure 14 are due to restrictions internal to the catapult between the propellant and the seat sequencer fitting. After the first static test the pressure transducer with pneumatic coupling was tested within Armstrong Laboratory to 2000 psi and found to operate satisfactorily. Verification of internal restrictions can only be verified by further testing of the catapult.

The first motion of the payload sled was delayed with respect to the zero-G condition in both the 3.5- and 7-G tests by as much as 56 msec as shown in Figure 15. This delay was the time required to generate adequate pressure to overcome the impressed load. The time of catapult strip-off was delayed by a maximum of 18 msec at the 3.5-G level and 28 msec at the 7-G level. The more rapid burning of the propellant under the impressed acceleration conditions tended to partially compensate for the initial delay in the seat motion by accelerating the seat more rapidly.

The internal pressures within the catapult measured during this test program exceeded 13,000 psi at the impressed acceleration level of 7 G. Pressures of 18,500 psi and 19,100 psi were measured during the lock-shut tests performed at the /S. A more gradual increase in pressure was expected under the impressed acceleration conditions unless the motion of the payload sled had been stalled by the impressed load.

The payload-sled acceleration increased more rapidly than simply predicted from the tests of the Talley 2400 series catapults. This relationship is shown in Figure 16. The higher increase of the payload-sled acceleration with increased impressed acceleration is attributed to two related factors, the operating pressure of the CKU-5/A catapult is higher and the burn rate of the catapult propellant increases as the pressure increases. For a given force the operating pressure of the CKU-5/A catapult must be higher since the diameter of the catapult tube and piston area are smaller than the Talley 2400 catapult (0.785 in^2 versus 4.076 in^2). Unfortunately, the burn rate of the propellant used in the CKU-5/A catapult is unknown above 7,500 psi. The CKU-5/A catapult operates at about 6,000 psi at zero G and at more than 11,000 psi and 13,000 psi under the 3.5- and 7-G impressed accelerations respectively. In contrast, the Talley 2400 series catapult operates at an average 1390 psi at zero-G and 2300 psi at 7 G.

The DRI values computed from the acceleration data are also higher under the impressed accelerations than had been expected. The worst that had

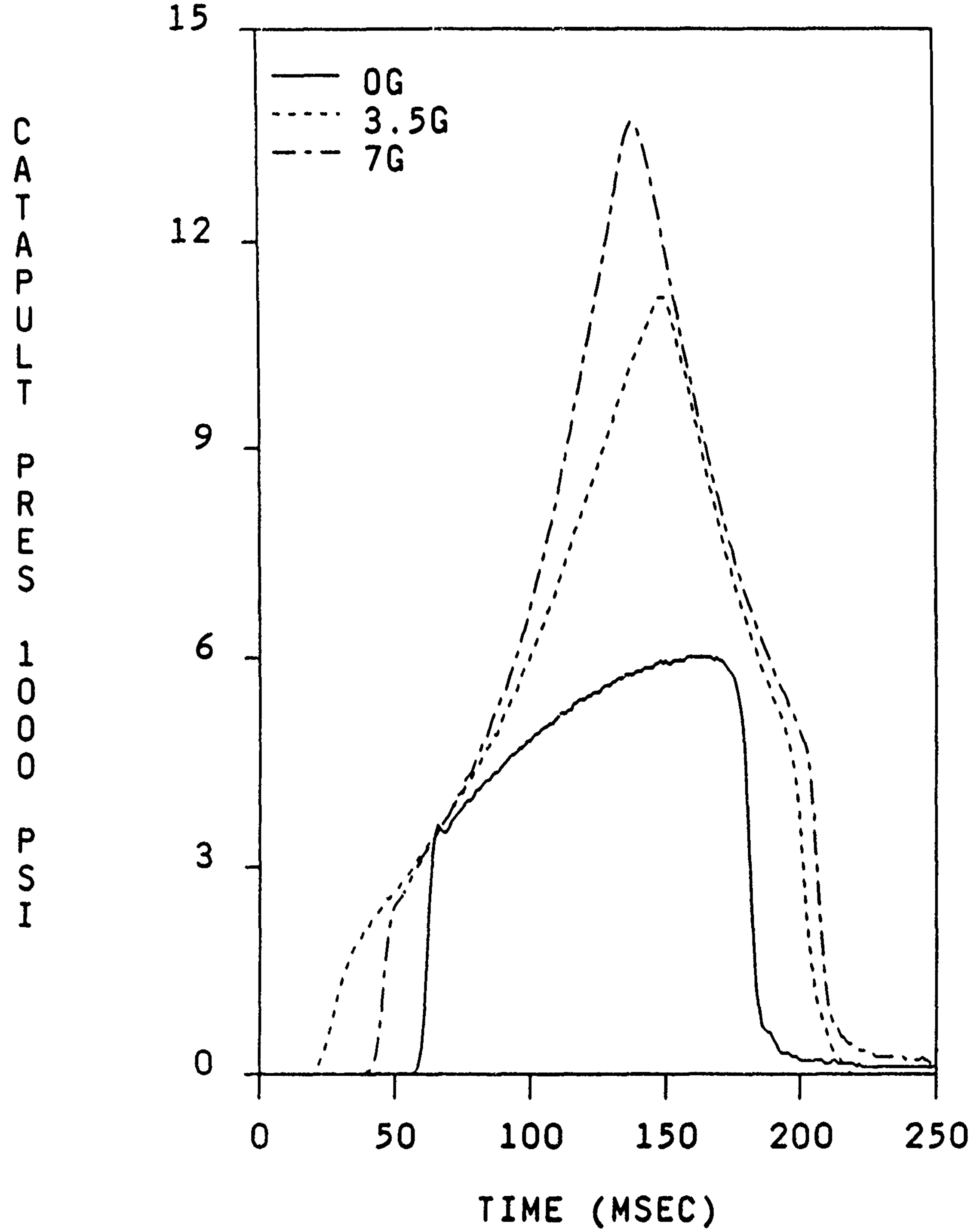

FIGURE 14. CATAPULT PRESSURE TIME HISTORIES FOR ZERO, 3.5 and 7 G TEST CONDITIONS

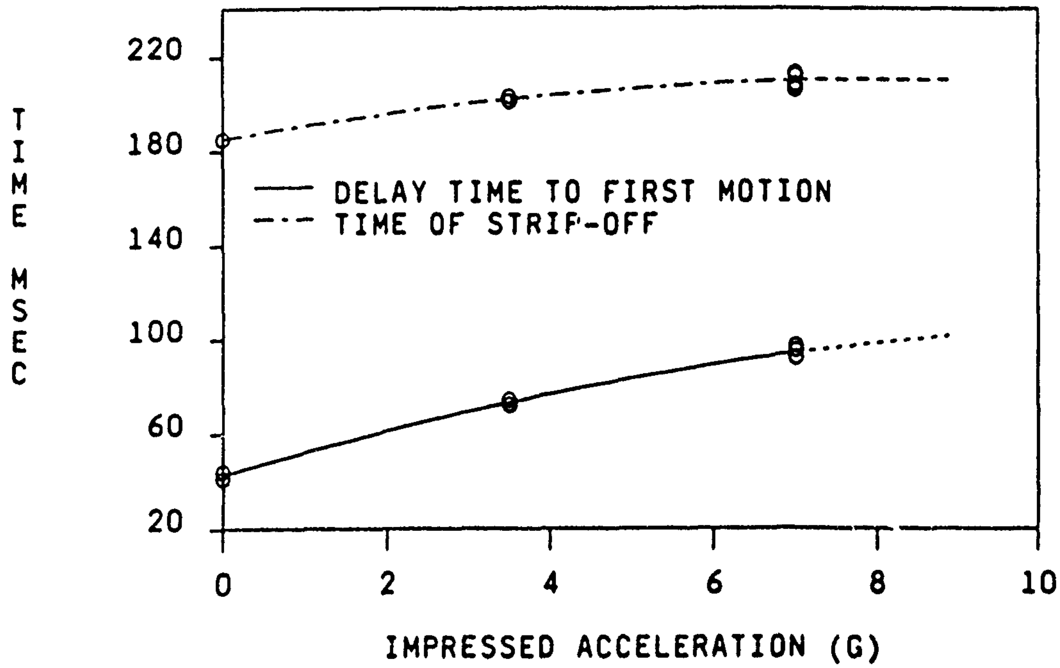

FIGURE 15. TIME DELAYS VERSUS IMPRESSED ACCELERATION LEVEL

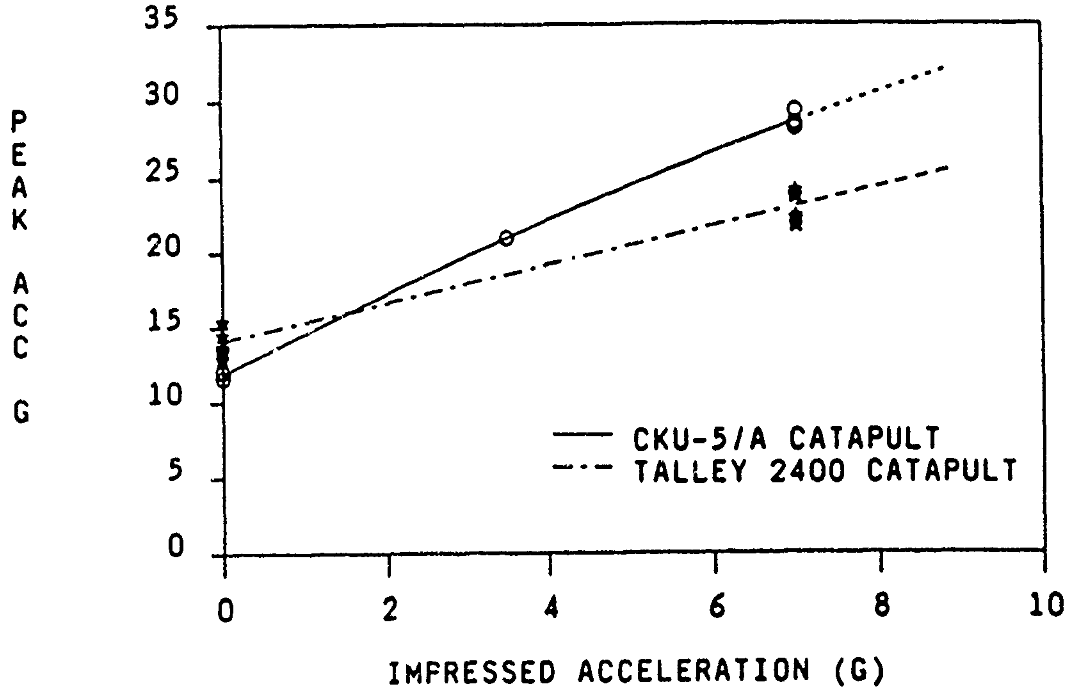

FIGURE 16. PEAK PAYLOAD SLED ACCELERATION AS A FUNCTION OF IMPRESSED ACCELERATION LEVEL FOR THE TALLEY 2400 AND CKU-5/A CATAPULTS

been anticipated was a factor of two increase, which would correspond to a spinal injury rate of approximately 50 percent. Unfortunately, the DRI values computed from the acceleration data from the tests at an impressed acceleration of 3.5 G nearly reached this level. This is an alarming finding. The fact that the DRI values averaged 30.6 at the 7-G level is even more alarming since it represents an extremely high probability of spinal injury. Unfortunately, the accuracy of the prediction of spinal injury rate and type of injury is not well known above the 50 percent probability level. There is evidence from accidents and tests with nonhuman primates that more severe types of spinal injury, including commutated fractures with spinal cord damage, can be expected at these higher DRI levels.

Limitations of the Results

There are several rather straightforward limitations of the test results that are related to the limitations of the test equipment. First, since only small numbers of catapults were available for the tests, the means and variance of the catapult performance parameters cannot be determined with good accuracy. This limitation does not detract from the general findings since the magnitudes of the effects that were observed are so large. Second, the tests were limited to impressed acceleration levels of 7 G due to the current restriction in the carrier sled brake system. Thus the question of whether the catapult may stall at the 9-G level is unanswered.

A second set of limitations of the experiment are less straightforward but should also be considered. First, the mass of the carrier sled and the friction of the brakes on the facility rails do not simulate the mass and aerodynamic characteristics of an aircraft. Therefore, the interaction between the carrier sled and the payload sled accelerations will not precisely duplicate the accelerations of an occupied ejection seat and an aircraft. This interaction effect is probably very small; nevertheless, it could be estimated by mathematical modeling techniques. Second, the payload sled is a rigid mass, but an ejection seat and especially its occupant are not. The dynamic response characteristics of an ejection seat and its occupant are known to cause the seat acceleration to vary from the waveforms seen in static tests or in the tests performed in this program. This effect can also be studied by mathematical modeling to estimate its influence. However, the influence of the seat and occupant dynamics is not expected to alter the overall findings of this report.

Extrapolation of the Test Data

In view of the evidence that the catapult propellant was expended prior to strip-off and the lack of data on the burn rate of the propellant at pressures above 7,500 psi, there is some risk in attempting to predict the performance of the CKU-5/A catapult directly from the data collected during this program. Extrapolation of the peak acceleration and time delays by using the least-squares-polynomial-regression technique should yield an estimate within 10 percent of actual as illustrated in Figures 15 and 16. However, other values such as catapult pressure and, to a less entent, strip-off velocity, shown in Figures 17 and 18, might be estimated with somewhat larger errors since the relationships between the impressed acceleration and these data do not appear to be as linear as the payload sled acceleration.

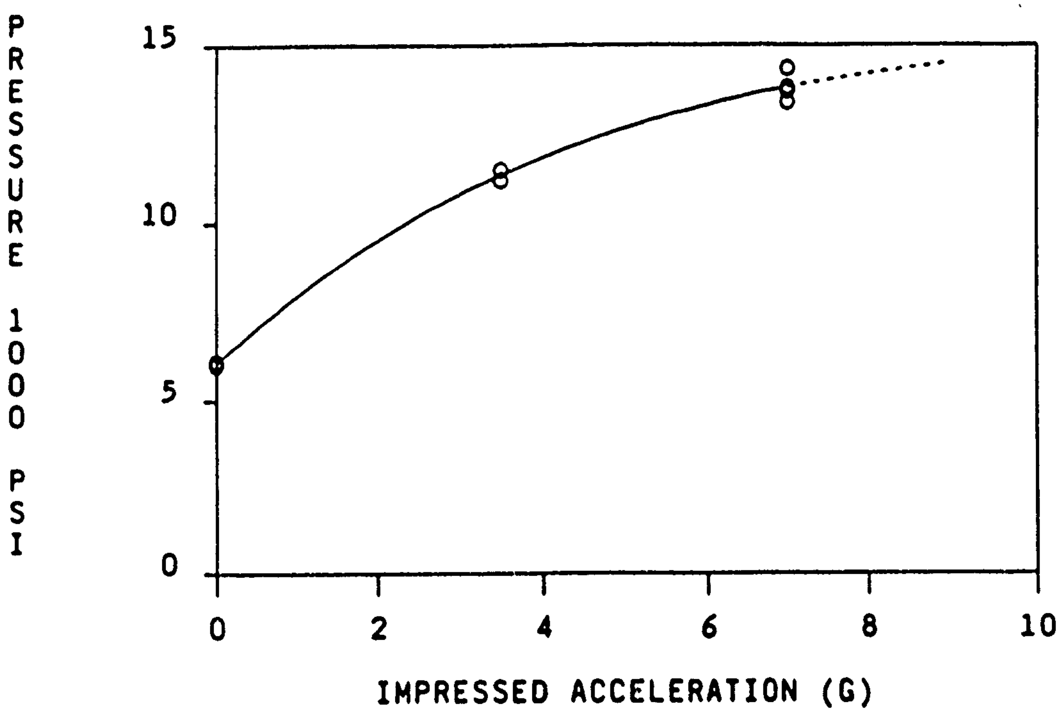

FIGURE 17. PEAK CATAPULT PRESSURE AS A FUNCTION OF IMPRESSED ACCELERATION LEVEL

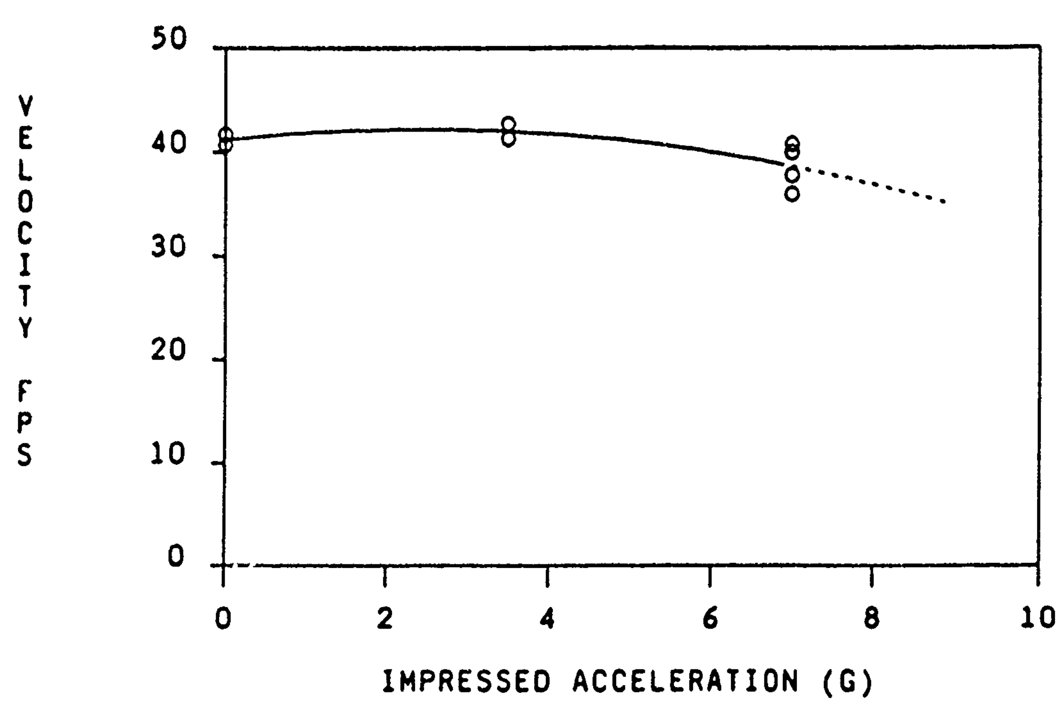

FIGURE 18. STRIP-OFF VELOCITY AS A FUNCTION OF IMPRESSED ACCELERATION LEVEL

In order to more accurately estimate the operational effects of the findings of this test program, performance analyses should be accomplished using mathematical models of the catapult, ejection seat, and seat occupant. As a first approach the catapult model developed by Higgins should be used with coefficient and parameter values derived from this test program. Ejection seat and seat occupant models are also available and would not require alteration. These analyses are essential to determine the likelihood of aircraft tail clearance under varied impressed accelerations and associated aircraft flight trajectories.

Operational Significance of the Findings

A fundamental question that must be answered to assess the importance of these test results is: What is the likelihood of ejection under impressed acceleration? Accident reports that are available at the time of this writing indicate that ejections have occurred under impressed acceleration. However, no recent studies have attempted to quantify the likelihood of their occurrence. Such an analysis is recommended.

SUMMARY

Conclusions

The following observations and conclusions were derived from the analysis of the test data:

1. The operational CKU-5/A ejection seat catapult will operate under an impressed +Gz acceleration of up to 7 G. The catapult will provide enough impetus to accomplish separation of the ejection seat/man from an aircraft.

2. All the performance parameters except the strip-off velocity of the CKU-5/A catapult were strongly affected by the impressed acceleration.

3. The mechanical clearances between the inner and outer tubes of the catapult did not cause statistically significant differences in the performance.

4. The probability of spinal injury increased to alarming rates as the impressed acceleration was increased.

Recommendations

The following recommendations are based upon the aforementioned results and evaluation of the data.

1. A study of operational aircraft accidents should be conducted to evaluate the probability of ejection under impressed acceleration.

2. If the probability of ejection under impressed acceleration is found to be high enough to be a significant concern to aircraft operators, the feasibility of redesigning the CKU-5/A catapult should be evaluated.

3. The results from this test program show that the current testing procedures used to qualify ejection seat catapults are inadequate to assess the effects of impressed acceleration on catapult performance. Catapult qualification test requirements should be modified to include tests under impressed acceleration.

4. Available propellant burn-rate data are limited to values obtained from tests up to pressures of 7500 psi. If the CKU-5/A catapult is to be modified or if new high-pressure catapults are to be developed in the future, a test method should be established and implemented to determine the burn-rate of the propellant at pressures up to 15,000 psi.

5. If the CKU-5/A catapult design is to be enhanced, additional testing should be accomplished to develop and verify a performance model of the catapult. The test matrix should include additional variables such as payload weight and temperature. Sufficient numbers of tests at each test condition should be accomplished to improve the statistical level of confidence in the data.

6. The performance of the ACES II ejection seat should be analyzed using mathematical modeling techniques to evaluate clearance of the seat and its occupant with the tail of the aircraft under varied levels of impressed aircraft acceleration.

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8. Volk, W. Applied Statistics for Engineers, McGraw-Hill Book Company, New York, 1969.

TEST CONFIGURATION AND DATA ACQUISITION SYSTEM FOR THE EVALUATION OF ACES II EJECTION SEAT CATAPULT IN ACCELERATION ENVIRONMENTS TEST PROGRAM

Prepared under
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INTRODUCTION

This report was prepared by DynCorp (formerly Dynalectron Corporation) for the Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL/BBP) under Air Force Contract F33615-86-C-0531.

The information provided herein describes the test facility, test fixtures, data acquisition systems, instrumentation procedures and the test configurations that were used in the Test Configuration and Data Acquisition System for the Evaluation of ACES II Ejection Seat Catapult in Acceleration Environments Test Program. The testing was done on the Horizontal Decelerator Facility during October and November 1987.

1. TEST FACILITY

The AAMRL Horizontal Decelerator Facility, shown in Figure A-1, was used for all of the thirty-three tests. The facility consists of the launch system, the track, an impact sled and the Hydraulic Decelerator.

The launch system, which is used to provide a controlled low acceleration launch of the impact sled, is shown in Figure A-2. Prior to launch, energy is stored in a flywheel that is driven by an electric motor. During a launch, the flywheel is coupled to a reel by an electronically controlled hydraulic clutch. Fabric tape, attached to the reel and the shuttle sled, is wound onto the reel to accelerate the shuttle sled which pushes the impact sled toward the Hydraulic Decelerator. The acceleration phase of the launch occurs for a distance of 73 to 75 feet. The impact sled then separates from the shuttle sled and coasts approximately 135 feet to the impact area.

The Hydraulic Decelerator is a horizontal cylinder bored within a series of steel blocks. The cylinder blocks are mounted within a water containment enclosure. At the point of impact, a 5 foot piston attached to the impact sled punctures a polyethylene retaining membrane and forces the water within the cylinder through orifices in the cylinder wall. In Figure A-3, the top of the water enclosure has been removed to show the positions of the orifice plugs that surround the cylinder block. The deceleration profile is controlled by varying the diameter of the orifices. Orifice profile number 1089 was used for this test program. Due to the special nature of this test program the Hydraulic Decelerator was used to provide an emergency braking device in the event the pneumatic braking system of the impact sled failed.

All tests accomplished on the Horizontal Decelerator Facility are initiated and controlled by the Master Safety and Control System. This system monitors the status of the critical launch system components, the sled velocity, the data acquisition systems and test area security. The system provides automatic test abort if the equipment status is unacceptable or if the Control Console Operator or Safety Officer release hand-held switches.

2. SLED FIXTURES

This test program required the use of two sleds, the Catapult Sled (herein referred to as the Payload Sled) and the Horizontal Accelerator Sled (herein referred to as the Carrier Sled).

The Catapult support weighs 50 lbs. and attaches to the Carrier Sled providing a rigid mount for the Catapult. It also mounts the pusher arms which engage the launch shuttle when used on the Horizontal Decelerator. The long tube extending from the base assembly contains the Catapult and is capable of withstanding the explosive forces that would be generated in the event that the Catapult ruptures during a test.

The Payload Sled can be seen in its final form in Figure A-4 with instrumentation, etc. in its test configuration. Figure A-5 illustrates the Carrier Sled separated from the Payload Sled and Figure A-6 shows the Horizontal Decelerator Shuttle, Payload Sled and Carrier Sled coupled together just prior to launch. The Payload Sled, configured for these tests, weighs 376 pounds which includes 30 lbs. of ballast weight. The Payload Sled slides on six two-inch diameter teflon glide pads at each corner (i.e., three glide pads on both the top and bottom surfaces of the rails).

The Payload Sled is also equipped with its own braking system, as shown in Figure A-4. The Payload Sled brake system is activated using a tether fastened to the base assembly and a phenolic pin at the valve. As the Payload Sled moves away from the Carrier Sled, the tether extends and pulls the pin. The valve then allows nitrogen to flow to the brake pads which clamp the rails and bring the sled to a stop. The brakes were installed with two valves which are activated separately to provide a redundant braking system.

The Carrier Sled is the standard Horizontal Accelerator Sled with a few modifications:

1) A 5 foot piston (Hydraulic Decelerator Ram) was attached to the sled to be used in conjunction with the Hydraulic Decelerator providing an emergency braking device in the event that the sled pneumatic braking system failed.
2) The new style Horizontal Accelerator Sled corner brakes, each with nine brake pads, were removed, and the old style corner brakes (reference Bendix drawing number D5505977), each with eleven brake pads, were installed. New brake pads were installed on the center and corner brakes. The new brake pad material is RF-38 non-asbestos molded lining as specified by AAMRL/BBP and purchased by DynCorp.
3) The current sled brake design allows a momentary brake application when the switch actuator arms move over the brake ramps. Because of the need for constant braking after the brakes are initially applied, a circuit was designed and implemented to allow for this constant braking requirement. Figure A-7 illustrates this circuitry.

3. TEST CONFIGURATIONS

Eight CKU-5/A Catapults, separated into two lots, were tested during this test program. One lot contained four catapults of maximum allowable clearance between the inner and the outer tube of the catapult. The second lot contained four catapults of minimum allowable clearance between the tubes.

The catapults were tested under both static and dynamic conditions. During the static tests (cells A and B) the Payload Sled was propelled from the Carrier Sled by the Catapult while the Carrier Sled was locked on the rails of the Horizontal Decelerator Track (Figure A-1) under the light rack (i.e., 0 G acceleration level). During the dynamic tests (cells C, D, G and H) the Payload and Carrier Sleds were launched down the track together by the Horizontal Decelerator Facility. The Payload Sled was propelled from the Carrier Sled by the Catapult when the Carrier Sled acceleration reached the specified G level at impact. The Catapult test conditions are shown in Table A-1.

TABLE A-1: CATAPULT TEST CONDITIONS

ACCELERATION LEVEL (G)	0	+3.5	+7
MINIMUM CLEARANCE	A	C	G
MAXIMUM CLEARANCE	B	D	H

The 0, 3.5 and 7 G test conditions were developed using the control parameters for the Horizontal Decelerator Facility Launching System, Carrier Sled and Brake Ramps as shown in Table A-2. These control parameters were developed and refined from profile tests 2074 through 2098 run without catapults.

4. CATAPULT IGNITION AND CONTROL

The Catapult Firing Circuit was developed by DynCorp personnel to provide catapult ignition for static or dynamic testing. Under dynamic conditions, the firing cannot take place until an additional deceleration condition occurs. The Holex Electrical Igniter Cartridge Model 6104 (Squib) was used with the M53 Initiator Cartridge on all tests.

The Catapult Firing Circuit, Figure A-8, provides contact closure for the Squib power source and provides additional safety circuits necessary in the use of explosive devices. A block diagram is shown in Figure A-9. The following conditions have to be made before a firing can commence. The Squib Power Supply Breaker must be on, Instrumentation Fire Enable switch on, Voltage on/off switch on, Facility Comparator on and Carrier

Sled deceleration satisfied. During dynamic testing, the Carrier Sled accelerometer signal is compared in the control circuit to a predetermined and preset voltage level representing G's. When the two signals combine algebraically to zero, the fire enable relays K2 and K3 are energized which turns on the fire relay K1 resulting in a current supplied to the squib at the Catapult Sled for firing. Static tests were set up for a T=0 firing while the dynamic test firing occurred between T + 7 and T + 9 seconds depending on sled velocity and acceleration required.

5. INSTRUMENTATION

All measurement instrumentation used in this test program is listed in Table A-3. This table designates the manufacturer, type, serial number, sensitivity and other pertinent data on each transducer used. Table A-4 lists the manufacturers' typical transducer specifications.

Accelerometers, load transducers, the pressure transducer and displacement transducers were chosen to provide the optimum resolution over the expected test range. Full scale data ranges were chosen to provide the expected full scale range plus 50% to assure the capture of peak signals. All transducer bridges were balanced for zero output prior to the start of each test.

The Center Reference Point (CRP) is located at the attachment point of the Carrier Sled load cell.

The accelerometers were wired to provide a negative output voltage when accelerations were applied in the -Z direction (downtrack) as shown in Figure A-1.

The load transducers used included two fixed load cells which were wired to provide a positive output from both load cells when the Catapult was fired.

The displacement transducer was wired to provide a positive output voltage when the Carrier and Payload Sleds separated after the catapult firing.

The velocity wheel tachometers were wired to provide a negative output voltage when the sleds traveled in the -Z direction (downtrack).

5.1 Accelerometers

Carrier Sled Z acceleration was measured using an Endevco 2262A-200 linear accelerometer. The accelerometer was mounted on an "L" bracket centered under the sled.

Payload Sled Z acceleration was measured using an Endevco 2262A-200 linear accelerometer. The accelerometer was mounted on the front mounting bracket for the air brake reservoir as shown in Figure A-10.

5.2 Load Transducers

Carrier Sled force and Payload Sled force were each measured using Strainsert FL25U-3SGKT load cells. The load transducer locations and dimensions are shown in Figure A-11.

5.3 Pressure Transducer

The Catapult Internal Gas Pressure was measured using a Kulite HKM-375-20000 pressure transducer. Figure A-4 shows the location of the pressure transducer.

5.4 Displacement Transducer

The Catapult extension displacement after firing was measured using a Houston Scientific 1850-50AD-SMM-50G displacement transducer. Figure A-4 shows the location of the displacement transducer.

5.5 Velocity Tachometers

Carrier Sled velocity and Payload Sled velocity were each measured using Globe Industries Model 22A672-2 tachometers. The rotor of each tachometer was attached to an aluminum wheel with a rubber O-ring around its circumference to assure good rail contact. The wheel contacted the track rail and rotated as the sled(s) moved, producing an output voltage proportional to the velocity.

Figure A-6 shows the location of the Carrier Sled Velocity Wheel. Figure A-4 shows the location of the Payload Sled Velocity Wheel and Figure A-12 shows a closer view.

5.6 Calibration

Calibrations were performed before and after testing to confirm the accuracy and functional characteristics of the accelerometers and velocity wheels. Pre-program and post-program calibrations are given in Table A-5.

The calibration of the accelerometers was performed by DynCorp using the comparison method (Ensor, 1970). A laboratory standard accelerometer, calibrated on a yearly basis by Endevco with standards traceable to the National Bureau of Standards, and a test accelerometer were mounted on a shaker table. The frequency response and phase shift of the test accelerometer were determined by driving the shaker table with a random noise generator and analyzing the outputs of the accelerometers with a PDP 11/15 computer and 1923 Time Data Unit using Fourier analysis. The natural frequency and the damping factor of the test accelerometer were determined, recorded and compared to previous calibration data for that test accelerometer. Sensitivities were calculated at 40 G and 100 Hertz. The sensitivity of the test accelerometer was determined by comparing its output to the output of the standard accelerometer.

The calibration of the Strainsert load cells and pressure transducer was performed by the Precision Measurement Equipment Laboratories (PMEL) at Wright-Patterson Air Force Base. PMEL calibrates these devices on a periodic basis and provides current sensitivity and linearity data.

The displacement transducer is periodically calibrated by DynCorp by fastening the transducer to a test fixture. A 36" metal ruler is used to measure the string displacement. As the string is pulled, the output of the transducer is monitored and voltages are recorded at every 2" increment. The linearity and sensitivity is obtained from this information.

The velocity wheel is calibrated periodically by DynCorp by rotating the wheel at approximately 2000, 4000 and 6000 revolutions per minute (RPM) and recording both the output voltage and the RPM.

6. DATA ACQUISITION

6.1 Analog Data Acquisition

Analog data acquisition were acquired initially using the Analog Data Acquisition System. After proper amplification and filtering, all data were recorded and stored on one inch analog tape using the Ampex FR2000 14-channel recorded via the Vidar multiplex system.

Quick-look data were required for each test to determine the quality of data collected and to determine that expected trends were being achieved. The Honeywell oscillograph was used to record data from the analog tape for visual readout.

Data acquisition was controlled by a comparator on the Master Instrumentation Control Unit in the Instrumentation Station. The comparator was set to start data collection at T-13 seconds and the test was initiated at T = 0 seconds. A reference pulse was electronically initiated to mark the electronic test data and initiate a strobe light in the test area to mark the film frame. The reference mark, used in the processing of data, was generated just prior to catapult firing. This was accomplished by placing the reference mark proximity switch adjacent to the brake ramps. The proximity switch was initiated when the Carrier Sled passed over the switch.

Timing pulses of 100 pps were provided by the master clock to the film data. The cameras were run at 500 frames per second and a timing pulse was placed on the film at 10 millisecond intervals.

6.2 Automatic Data Acquisition and Control System (ADACS)

The Automatic Data Acquisition and Control System (ADACS) was used to digitize the analog magnetic tape data. Eleven channels were used, ten for data transfer and one for the reference mark. A total of two passes

were made for each test. One pass recovered the zero data and the other pass recovered the impact data. The reference mark was digitized on all impact data passes to provide a common reference point.

After the data had been transferred from analog tape to digital tape, a computer program was used to retrieve all data in a format suitable for publishing.

6.3 Photo Data Acquisition

Photo Data Acquisition was accomplished with one off-board 16mm high-speed LOCAM model 164-5AC camera (SN 194) using a 9mm lens (SN 72019) and operating at 500 frames per second. The camera was rigidly attached to a mounting bracket located on the left (end) support post of light rack number 1, 29.5 inches off the floor and positioned at right angles to the event with the sled separation near the center of the field of view of the camera. One on-board high-speed (500 frames per second) LOCAM model 50-0002 camera (SN 373) using a 10mm lens (SN 1061709) was mounted on the Carrier Sled at an oblique angle, as can be seen in Figure A-6, and was used for documentation purposes.

The cameras were automatically started at a preset time in the test sequence by a signal from the camera and lighting control station.

Ten fixed fiducials were used, each being a 1.25 inch diameter black circle on a 2.00 inch diameter white target, and were placed on the two sleds to allow tracking of displacement during sled separation. Figure A-13 identifies the fiducial target locations.

The photogrammetric data were time correlated in each test. Immediately prior to catapult firing, a reference mark signal triggered the flash unit to mark the camera film frame. At that time a 100 PPS signal was switched to the camera Light Emiting Diode (LED) driver which activated the camera LED, producing a time mark at the film edge. This reference mark was then used to correlate the photogrammetric data with the electronically measured data. The photogrammetric data were processed as required on the Automatic Film Reader (AFR) System.

An Instant Analytical Replay (INSTAR) video system was also used to provide coverage of each test. This video recorder and display unit is capable of recording high speed motion at a rate of 120 frames per second. Immediate replay of the sled separation is possible in real time or in slow motion.

7. PROCESSING PROGRAMS

The executable images for the processing programs are located in directory PROCESS of the VAX 11/750 and the test data is assumed to be stored in directory DATA1. All plots are output to the Tektronix

hardcopy unit and the test summary sheet is listed to the Printronix P300 line printer. The test base file is output to directory PROCESS.

7.1 Program Operation

The two Fortran programs that process the test data are named ACES2HDC0A and ACES2HDC0B. The DCL file which controls the execution of these programs is named ACES2HDC. The character string "ACES2" identifies the study (ACES II Catapult Study), "HDC" identifies the facility (Horizontal Decelerator), "0" is the revision number and the last character determines the program order of execution.

ACES2HDC0A creates a temporary DCL file which controls the sequential batch processing of a specified number of tests. ACES2HDC0A requests the user to enter the total number of tests to be processed and the test number for each test. Directory DATA1 is assumed to contain a zero reference file named '<test no>Z.LGD,' a test data file named '<test no>D.LGD' and a sensitivity file named '<test no>S.LGD.' The user enters the test number, test date, acceleration field, catapult serial number and tolerance. ACES2HDC0A reads the channel sensitivities, amplifier gains, offsets and descriptions from the test sensitivity file.

ACES2HDC0B does the actual data processing of the test data. The test data includes the payload sled Z acceleration, velocity and force and the carrier sled z acceleration, velocity and force. The catapult pressure and displacement are also included. The strip off time, strip off velocity, carrier sled acceleration at maximum payload acceleration, catapult separation rate, dynamic response index and delay time to first motion are computed based on the test data.

The output of ACES2HDC0B consists of a base file, summary sheet and plots. The base file contains the extrema for the individual channels and the derived quantities. The summary sheet displays the extrema in a more readable format. The time histories of the parameters are plotted on the Tektronix terminal and hardcopied.

7.2 Program Flowcharts

Flowcharts of the two programs are shown in Figures 14 and 15. Each flowchart identifies the files used and the subroutines called by the program. Some of the subroutines which are not flowcharted are located in user libraries. Others have such a simple structure that they do not require flowcharting.

TEST NUMBER	2099	2100	2101	2102	2103	2104	2105	2106
CELL TYPE	A	B	G	H	G	H	C	D
ACCELERATION LEVEL (G)	Ø	Ø	7	7	7	7	3.5	3.5
INITIAL FLYWHEEL SPEED (RPM)	-	-	925	925	925	925	595	595
SEPARATION FLYWHEEL SPEED (RPM)	-	-	656	655	656	660	395	384
MAXIMUM CLUTCH PRESSURE (PSI)	-	.	750	750	750	750	550	550
REEL BRAKE PRESSURE (PSI)	-	-	400	400	400	400	350	350
RETRACT CABLE STATIC PRESSURE (PSI)	-	-	90	90	90	90	115	115
MAXIMUM RETRACT CABLE BRAKE PRESSURE (PSI)	-	-	650	650	650	650	350	350
INITIAL CLUTCH PRESSURE (PSI)	-	-	200	200	200	200	200	200
INITIAL GAIN	-	-	0.1	0.1	0.1	0.1	0.1	0.1
FINAL GAIN	-	-	2.53	2.53	2.58	2.57	1.40	1.40
PEAK END VOLTS	-	-	1.0	1.0	1.0	1.0	0.4	0.4
TACH VOLTS	-	-	350	350	350	350	350	350
CARRIER SLED BRAKE PRESSURE (PSI)	700	700	615	615	615	615	280	280
CARRIER SLED VELOCITY AT BRAKE INITIATION (FPS)	-	-	93.0	93.0	98.0	94.0	38.0	38.0
VELOCITY COMPARATOR	-	-	110.0	110.0	110.0	110.0	65.0	65.0
BRAKE RAMP LOCATION*	-	-	58'6"	57'6"	57'6"	57'6"	45'6"	40'6"

*NOTE: BRAKE RAMP LOCATION IS DEFINED AS THE LOCATION WHERE THE CARRIER SLED BRAKES ARE INITIATED BY THE LEADING EDGE OF THE RAMP. THE LOCATION IS REFERENCED FROM THE HORIZONTAL ACCELERATOR END OF THE TRACK.

TABLE A-2: TEST CONTROL PARAMETERS

INSTRUMENTATION REQUIREMENTS

DYNALECTRON CORPORATION

PROGRAM: ACES II CATAPULT TESTING DATE: 22 OCT 87 THRU: 24 NOV 87

FACILITY: HORIZONTAL DECELERATOR RUN: 2074 THRU: 2106

DATA CHANNEL	DATA POINT	XDUCER MFG & TYPE	S/N	XDUCER SENS	EXCITE V	CHAN	CAL PROGRAM	AMPLIFIER MFG & S/N	AMP GAIN	F S SENS = 1 VOLT	FILTER	VCO	MUX NO	TAPE REC CH	TYPE DIR/FM	SPECIAL NOTATIONS
1	CARRIER SLED Z	ENDEVCO 2262 A-200	FR31	5.041 mv/G	10.050	1	100% = 25G	NEWPORT 1	7.93	25G	3K	1	1	1	DIR.	
2	PAYLOAD SLED Z	ENDEVCO 2262 A-200	KJ75	3.355 mv/G	10.055	2	100% = 40G	NEWPORT 2	7.45	40G	3K	2	1	1	DIR.	
3	CARRIER FORCE	STRAINSERT FL25U-3 SGKT	4030-1	1.804 uv/Lb	15.390	3	100% = 10,000 Lb	NEWPORT 3	55.43	10,000 Lb	3K	3	1	1	DIR.	TENS. CAL USED @ 10K
4	PAYLOAD FORCE	STRAINSERT FL25U-3 SGKT	4030-2	1.831 uv/Lb	15.430	4	100% = 10,000 Lb	NEWPORT 4	54.62	10,000 Lb	3K	4	1	1	DIR.	COMP. CAL USED @ 10K
5	CATAPULT PRESSURE	KULITE HKM-375-20000	126 6-8-380	3.619 uv/PSI	10.040	5	100% = 20,000PSI	NEWPORT 5	13.82	20,000 PSI	3K	5	1	1	DIR.	
6	DISPLACE-MENT	H.S. 185 0-50AD-S MM-50G	545 5-001	0.020 mv/INCH	1.041	6	-	-	-	50 INCH	3K	6	1	1	DIR.	
7	PAYLOAD SLED VELOCITY	GLOBE 22 A672-2	5	0.0100 V/F/S	-	-	-	-	-	100 F/S	-	7	1	1	DIR.	ATTENUATOR SET @ 1 VOLT IN = 0.04857 VOLT OUT SENSITIVITY=0.2059 V/F/S 0.2059÷20.59 = 0.0100 V/F/S
VTD OUTPUT	CARRIER SLED VELOCITY	GLOBE 22 A672-2	2	0.0100 V/F/S	-	-	-	-	-	100 F/S	-	1	2	2	DIR.	VTD OUTPUT SCALED TO 100 FT/VOLT RAW TACH OUTPUT 0.1770 V/F/S 2074-2086; 2087 AND SUBSEQUENT @ 0.175 V/F/S
SQUIB CTL	SQUIB EVENT	-	-	1 VOLT	-	-	-					2	2	2	DIR.	ATTENUATOR SET @ 20:1
SQUIB CTL	FIRE INITIATION	-	-	1 VOLT	-	-	-					3	2	2	DIR.	ATTENUATOR SET @ 10:1
	EVENT	-	-	-	-	-	-	-	-	-	-	-	-	10	FM	
	TIMING											-	-	13	FM	
	VOICE											-	-	14	FM	

TAPE RECORDER TIME ON -13 OFF +14 SPEED 60 IPS MUX CAL ±1 VOLT=±8KHz DEVIATION

POLARITIES. ACCELERATION DOWNTRACK IS NEGATIVE
VLLOCITY DOWNTRACK IS NEGATIVE
FORCES AT CATAPULT FIRING IS POSITIVE

STATIC TESTS: 2099, 2100
DYNAMIC TESTS - 2101 THRU 2106

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TABLE A-3: INSTRUMENTATION REQUIREMENTS

TYPICAL TRANSDUCER SPECIFICATIONS

MANUFACTURER	MODEL	RANGE	SENSITIVITY (mv)	RESONANCE FREQ (Hz.)	FREQUENCY RESPONSE (Hz.)	EXCITATION (Volt)	2 ARM OR 4 ARM	ADDITIONAL NOTES
Endevco	2262A-200	±200G	2.5/G	7000	0-1800	10	4 arm	Linear accelerometer, .7 damping ratio
Kulite	HKM-375-20000	20000 PSI	0.0036/PSI	395K	>50K	10	4 arm	Pressure transducer; 15 V max exc.; 35000 PSI max overrange
Strainsert	FL25U-3SGKT	±25,000 Lb	0.0018/Lb	3600	0-2000	10	4 arm	Load cell; 15 V max exc.; 50 K LB max. overrange
Houston Scientific International	1850-50AD-SMM-50G	50 inches	*/in	-	-	1.0	-	Displacement transducer; 20 V MAX EXC.; * Nominal Sensitivity is directly proportional to excitation voltage divided by 50

TABLE A-4: TYPICAL TRANSDUCER SPECIFICATIONS

PROGRAM CALIBRATION LOG

PROGRAM: ACES II CATAPULT TESTING **DATES:** 22 OCT 87 - 24 NOV 87

FACILITY: HORIZONTAL DECELERATOR **RUN NUMBERS:** 2074 - 2106

DATA POINT	TRANSDUCER MFG. & MODEL	SERIAL NUMBER	PRE-CAL		POST-CAL		% CHANGE	NOTES
			DATE	SENS	DATE	SENS		
CARRIER SLED Z	ENDEVCO 2262A-200	FR31	16OCT87	5.041 mv/G	24DEC87	5.039 mv/G	-0-	
PAYLOAD SLED Z	ENDEVCO 2262A-200	KJ75	16OCT87	3.355 mv/G	23DEC87	3.339 mv/G	-0.5	
*CARRIER FORCE	STRAINSERT FL25u-3SGKT	4030-1	08SEP87	1.804 uv/Lb.	-	-	-	
*PAYLOAD FORCE	STRAINSERT FL25U-3SGKT	4030-2	08SEP87	1.831 uv/Lb.	-	-	-	
*CATAPULT PRESSURE	KULITE HKM-375-20000	1266-8-380	10MAR87	3.619 uv/PSI	-	-	-	
*DISPLACEMENT	H.S. 1850-50AD-SMM-50G	5455-001	26OCT87	20.0 mv/in	-	-	-	
PAYLOAD SLED VELOCITY	GLOBE 22A672-2	5	14OCT87	0.1759 V/REV/S	05JAN88	0.1777 V/REV/S	+1.0	
CARRIER SLED VELOCITY	GLOBE 22A672-2	2	11SEP87	0.1512 V/REV/S	05JAN88	0.1521 V/REV/S	+0.6	
					*	CALIBRATED PERIODICALLY, POST-CALIBRATION NOT REQUIRED.		

TABLE A-5: TRANSDUCER PRE- AND POST-CALIBRATION

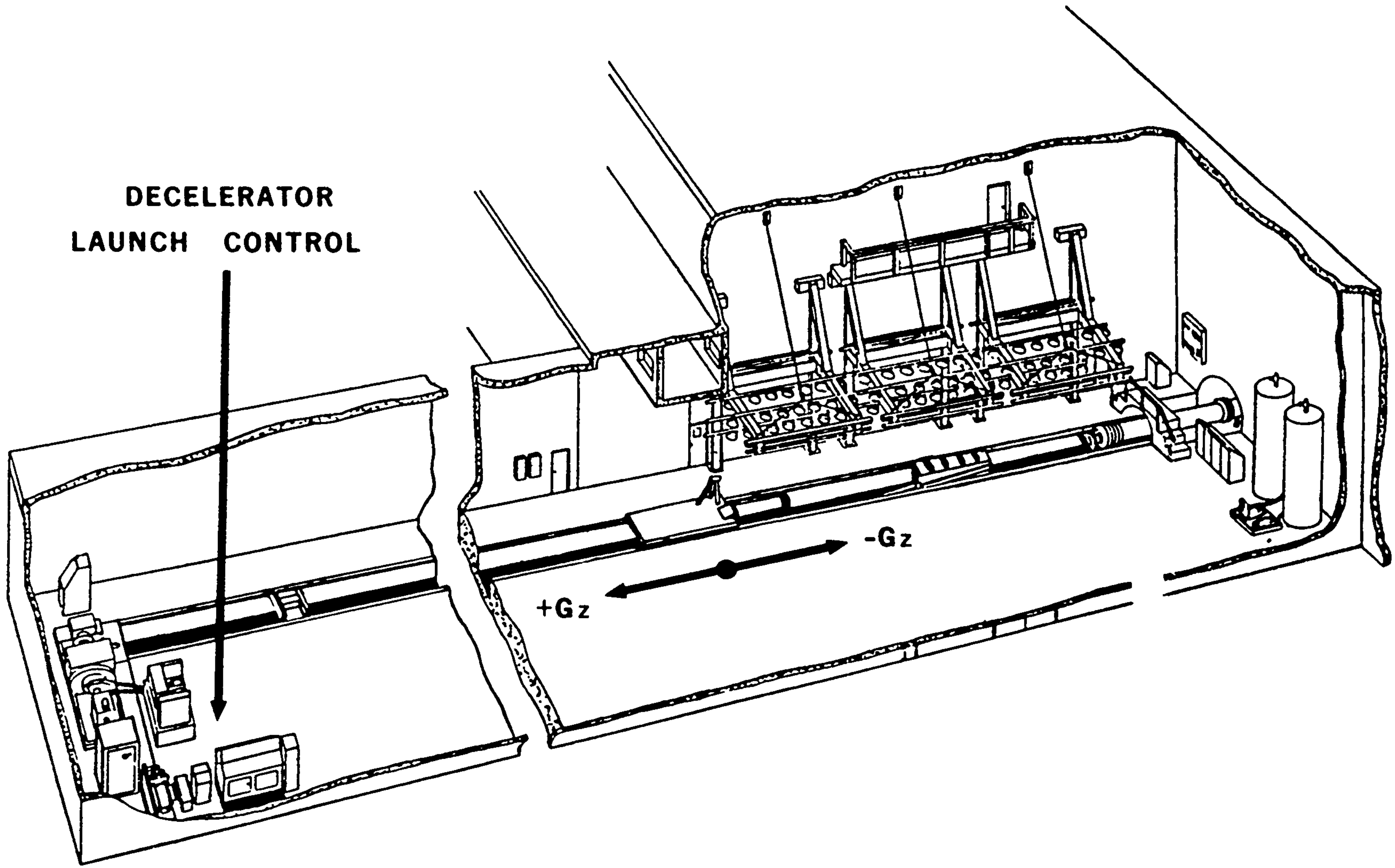


FIGURE A-1: AAMRL HORIZONTAL DECELERATOR FACILITY

FIGURE A-2: AAMRL HORIZONTAL DECELERATOR LAUNCH SYSTEM

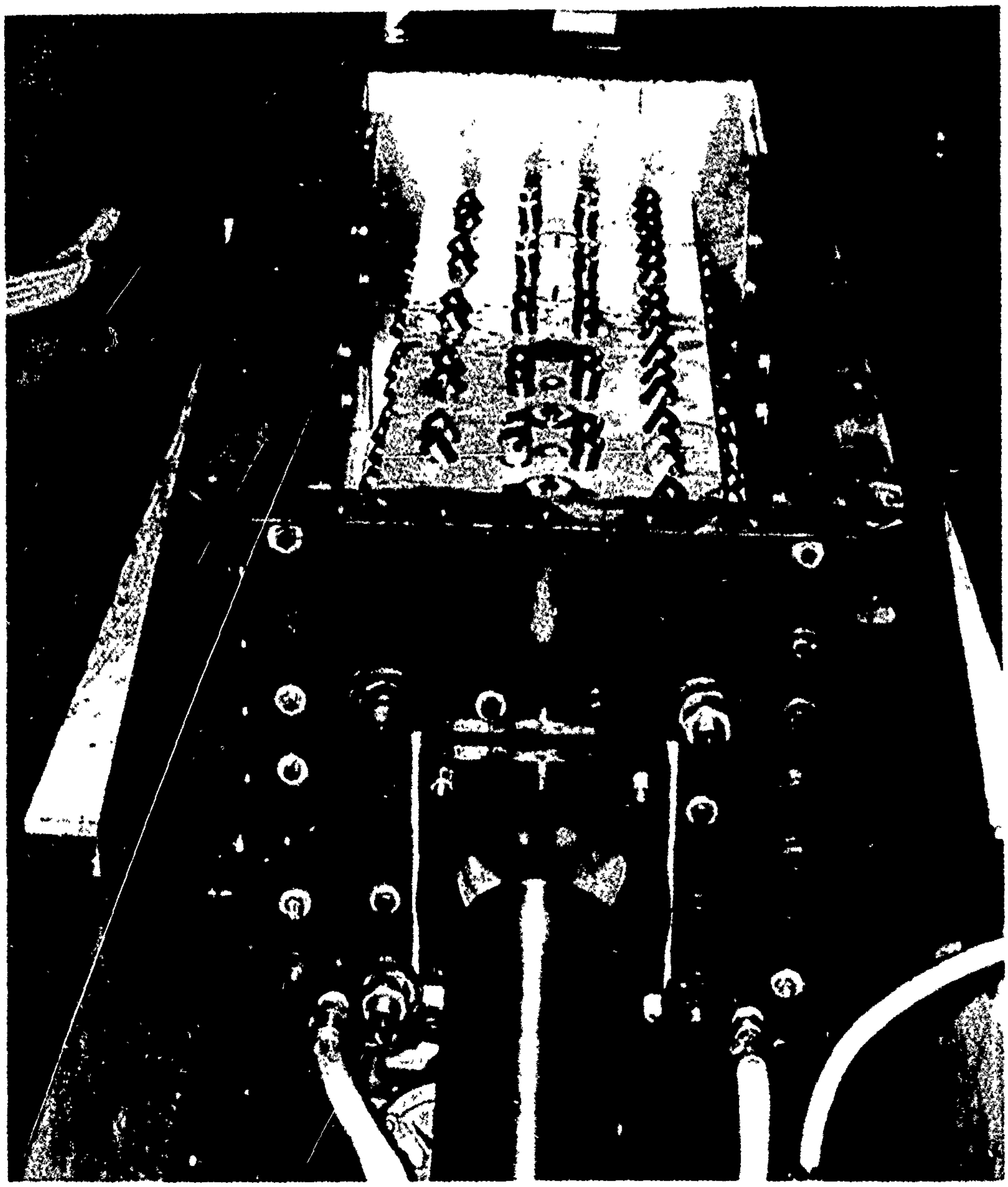


FIGURE A-3: HYDRAULIC DECELERATOR WITH TOP OF WATER ENCLOSURE REMOVED

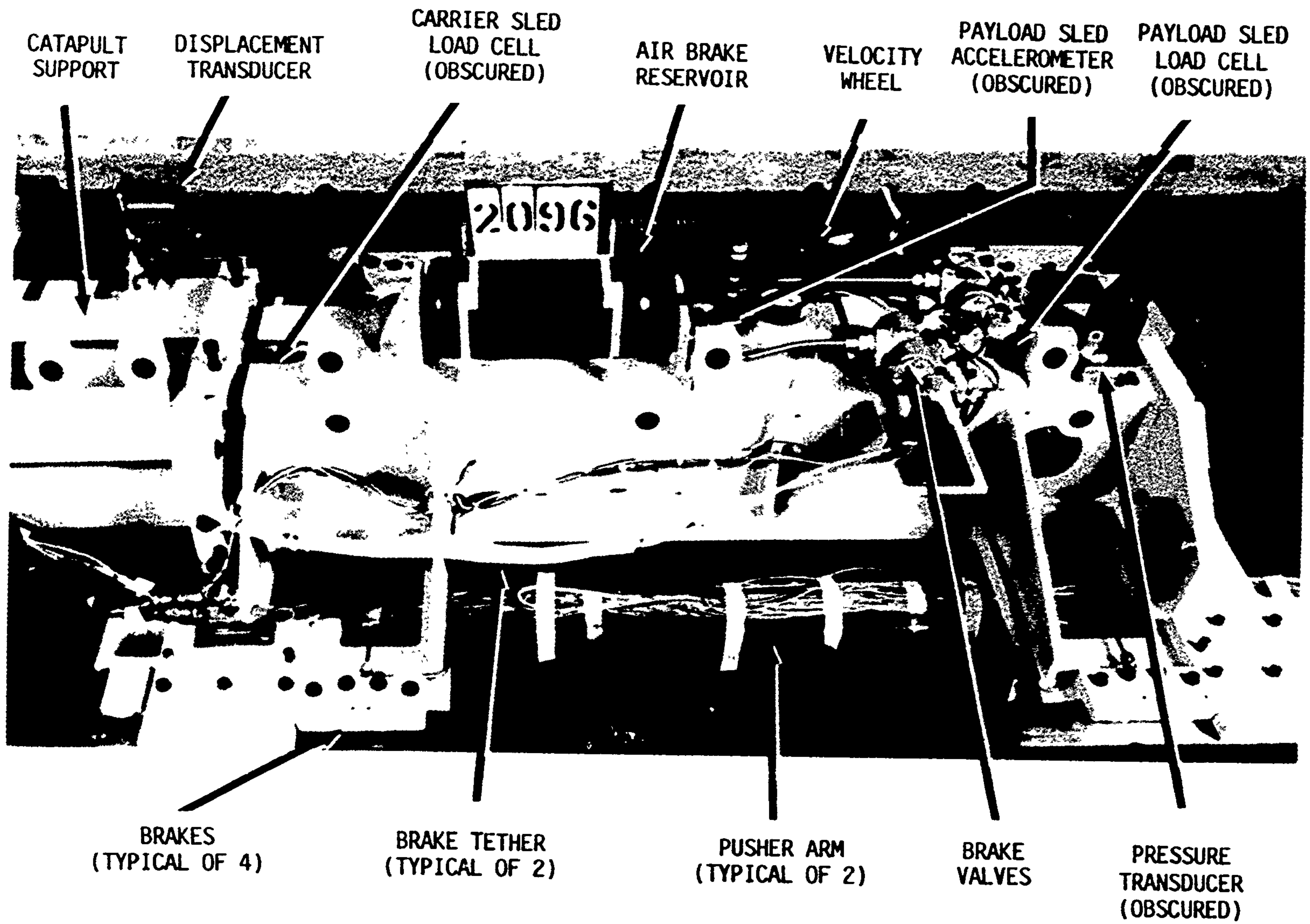


FIGURE A-4: PAYLOAD SLED FIXTURE

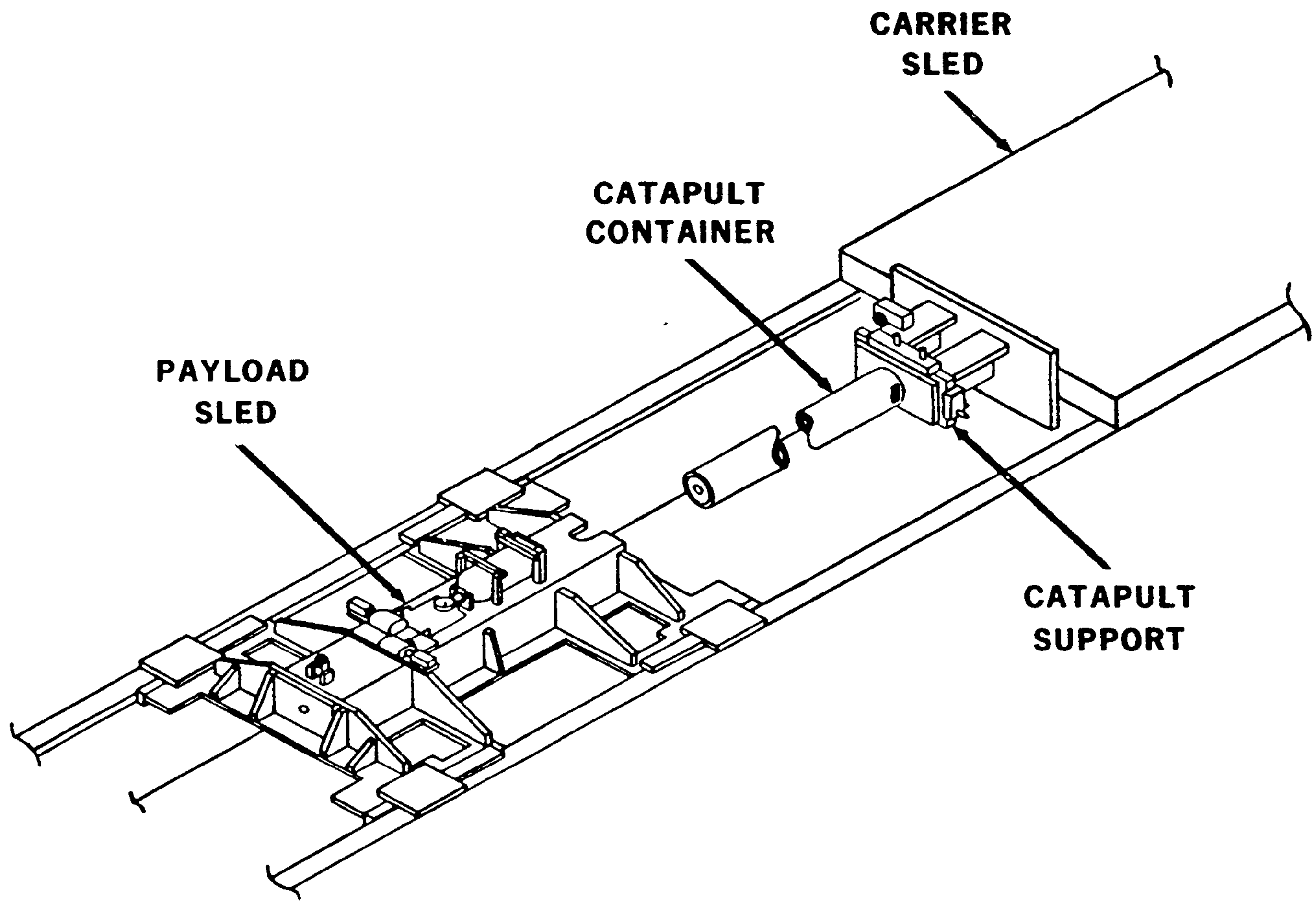


FIGURE A-5: PAYLOAD/CARRIER SLED TEST CONFIGURATION

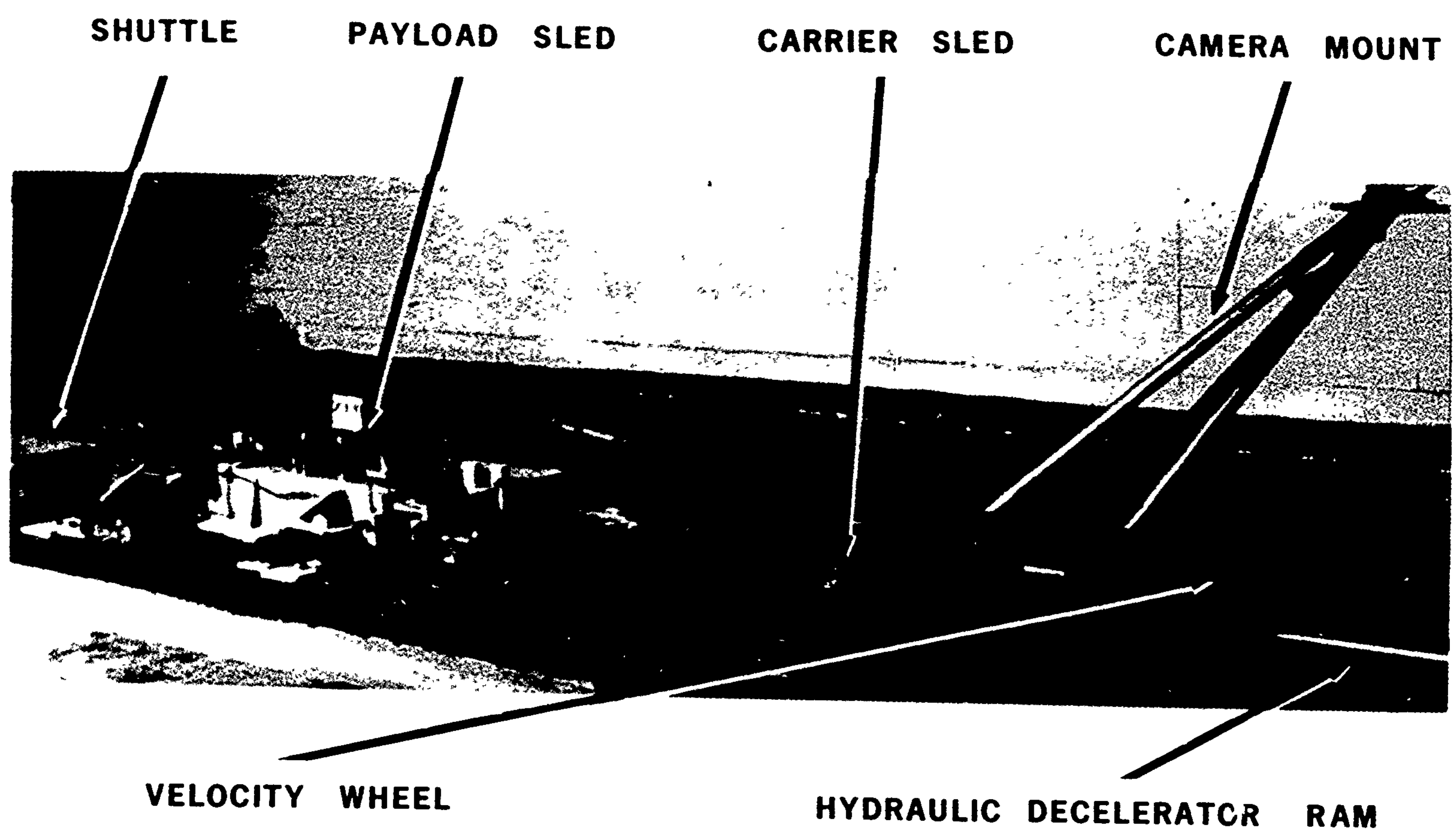


FIGURE A-6: SHUTTLE/PAYLOAD/CARRIER SLEDS PRIOR TO LAUNCH

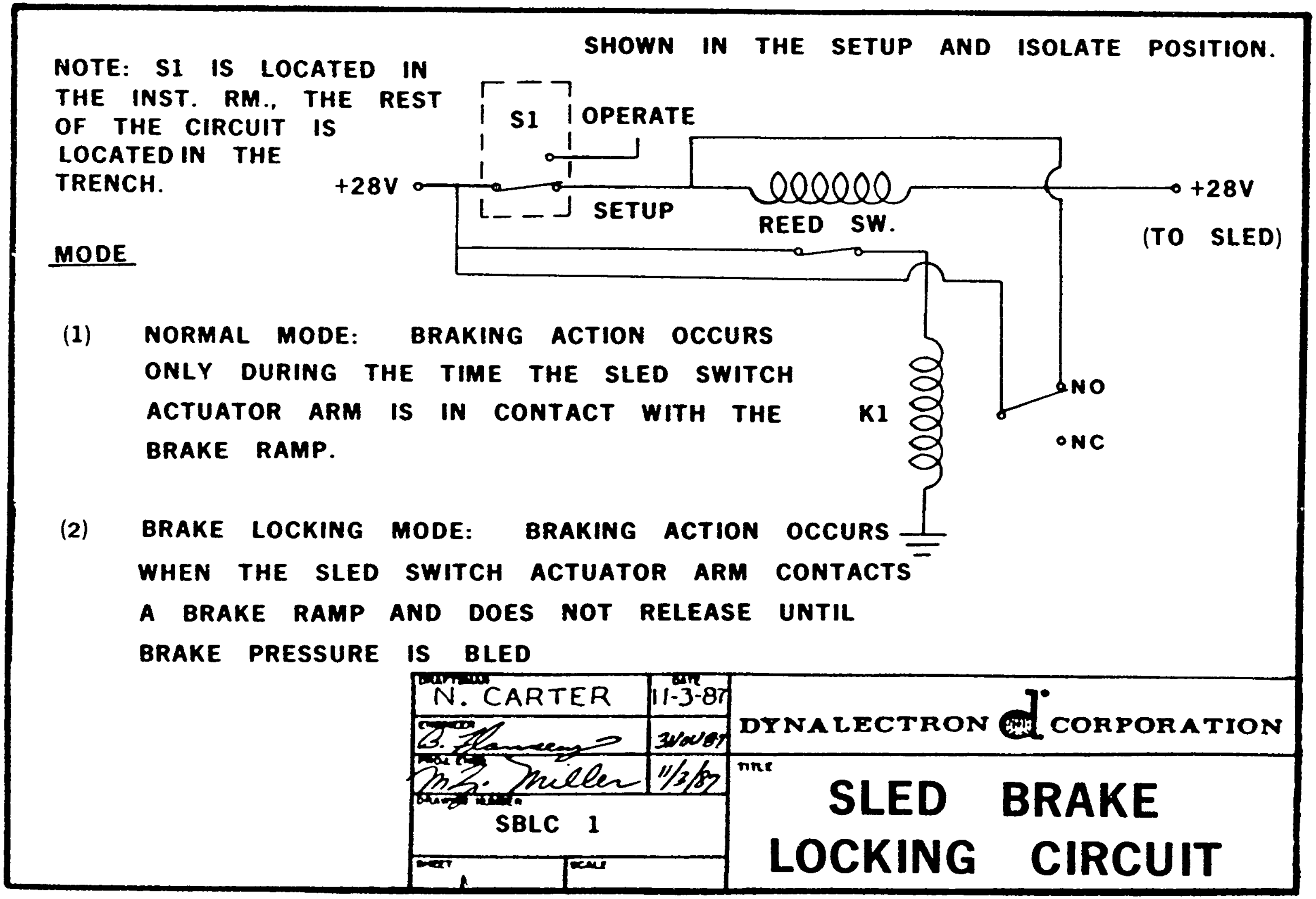


FIGURE A-7: SLED BRAKE LOCKING CIRCUIT

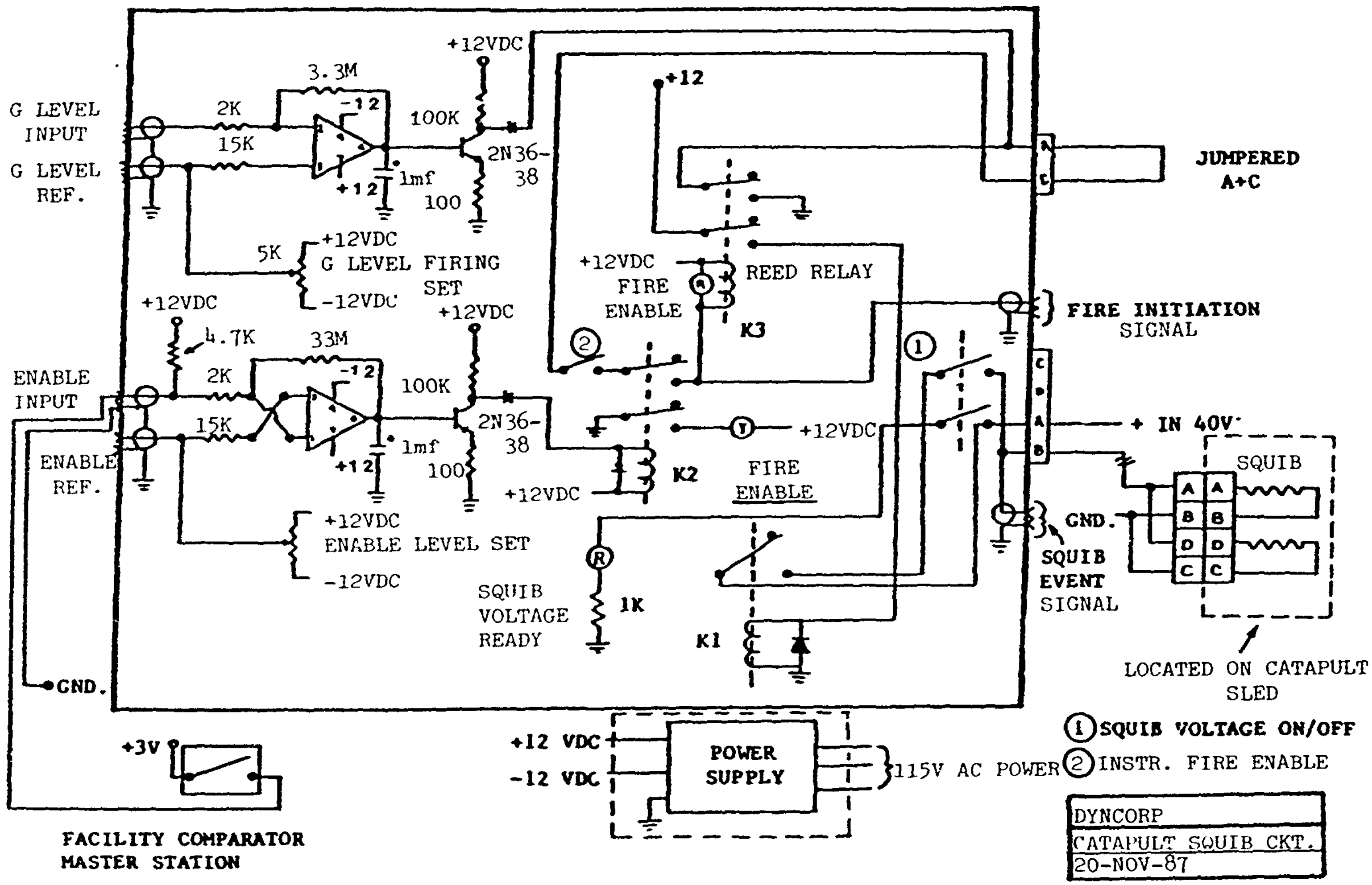


FIGURE A-8: CATAPULT FIRING CIRCUIT

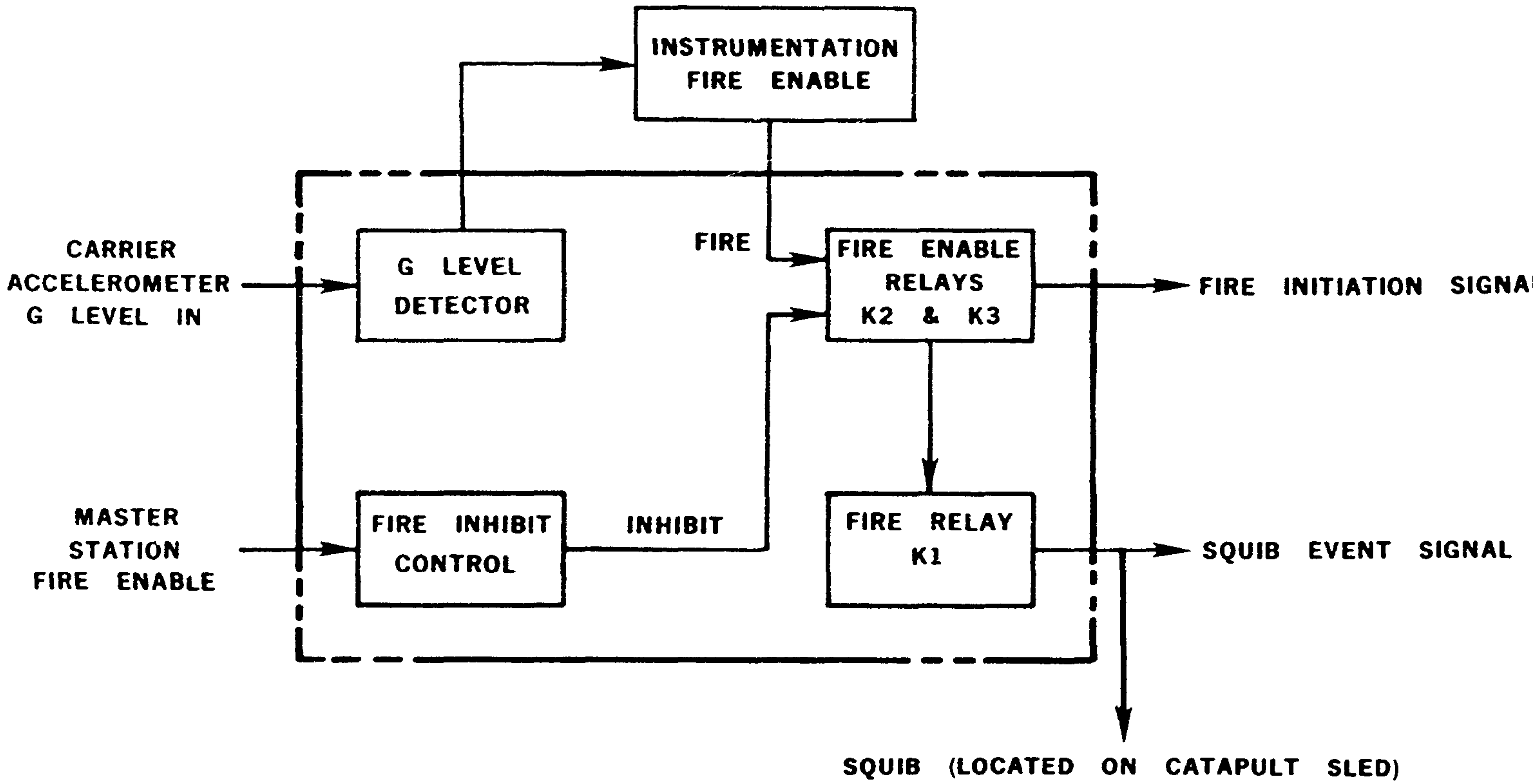


FIGURE A-9: CATAPULT CONTROL CIRCUIT - BLOCK DIAGRAM

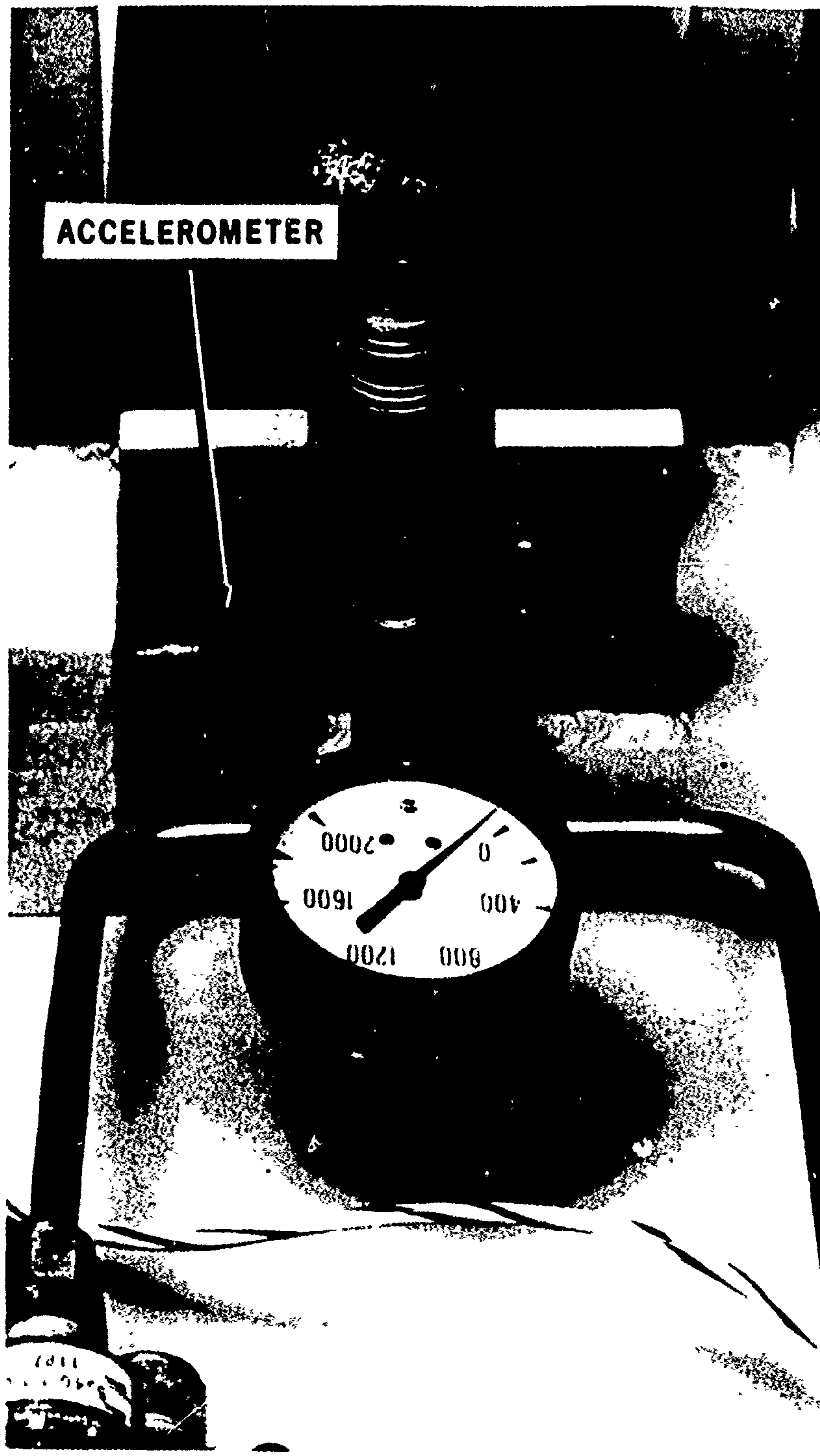
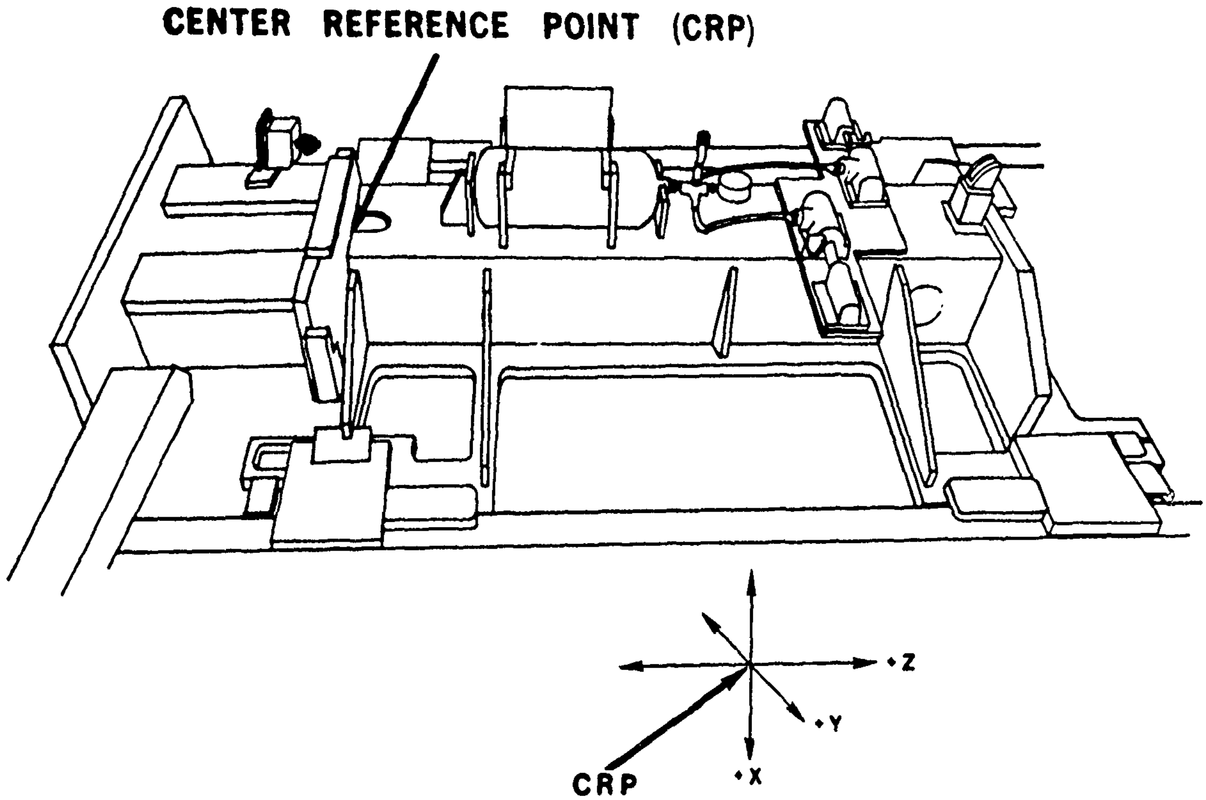


FIGURE A-10: PAYLOAD SLED Z ACCELEROMETER MOUNTING



LOAD CELL DESCRIPTION AND LOCATION

DESCRIPTION	DIMENSIONS IN INCHES		
	X	Y	Z
Center Reference Point	0.0	0.0	0.0
Carrier Sled Load Cell	0.0	0.0	0.0
Payload Sled Load Cell	0.0	0.0	49.12 (124.76 cm)

All dimensions are referenced to the Center Reference Point (CRP). The Center Reference Point is located at the attachment point of the Carrier Sled Load Cell. Load Cell dimensions are measured at their respective attachment points.

FIGURE A-11: LOAD TRANSDUCER LOCATIONS AND DIMENSIONS

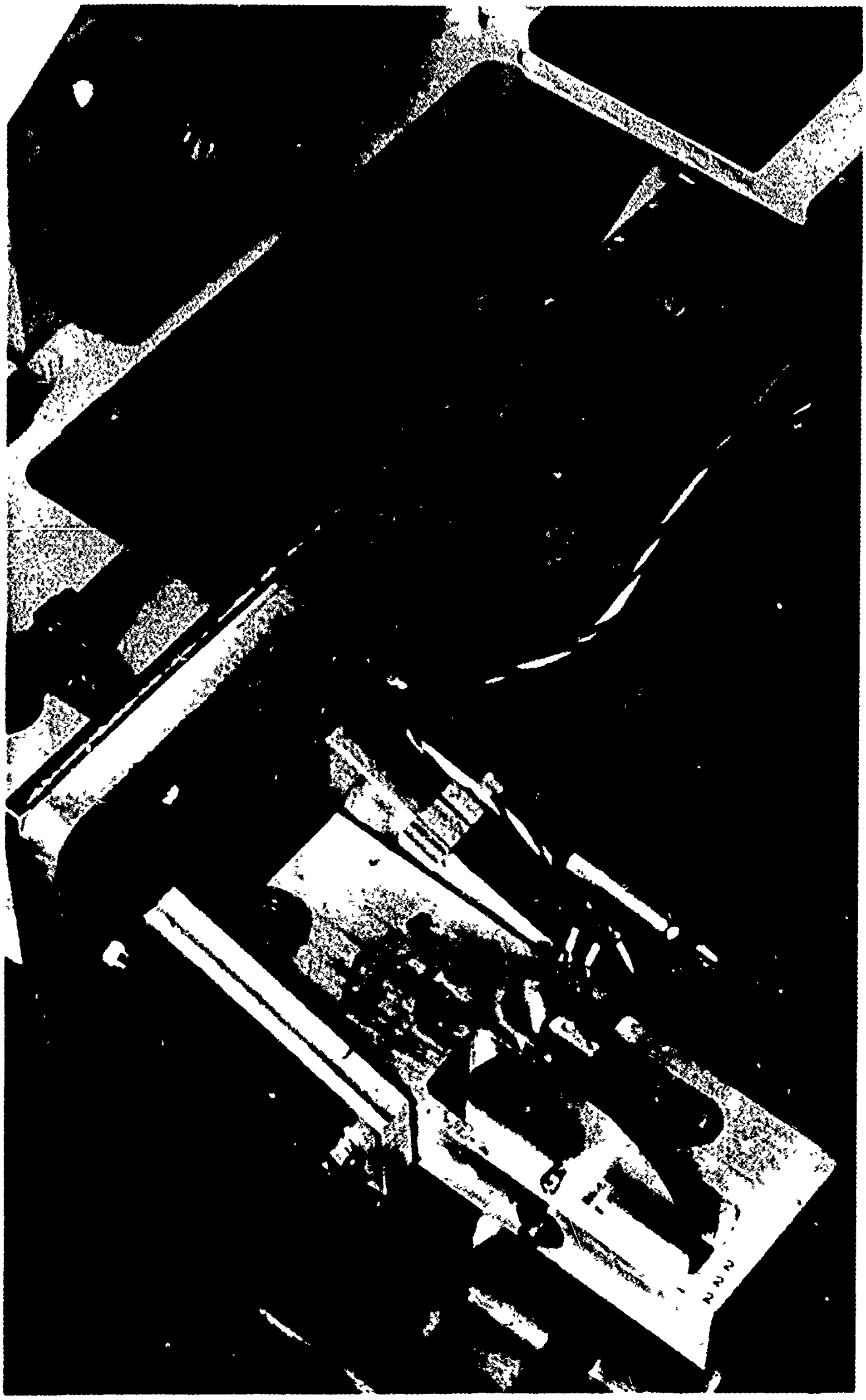
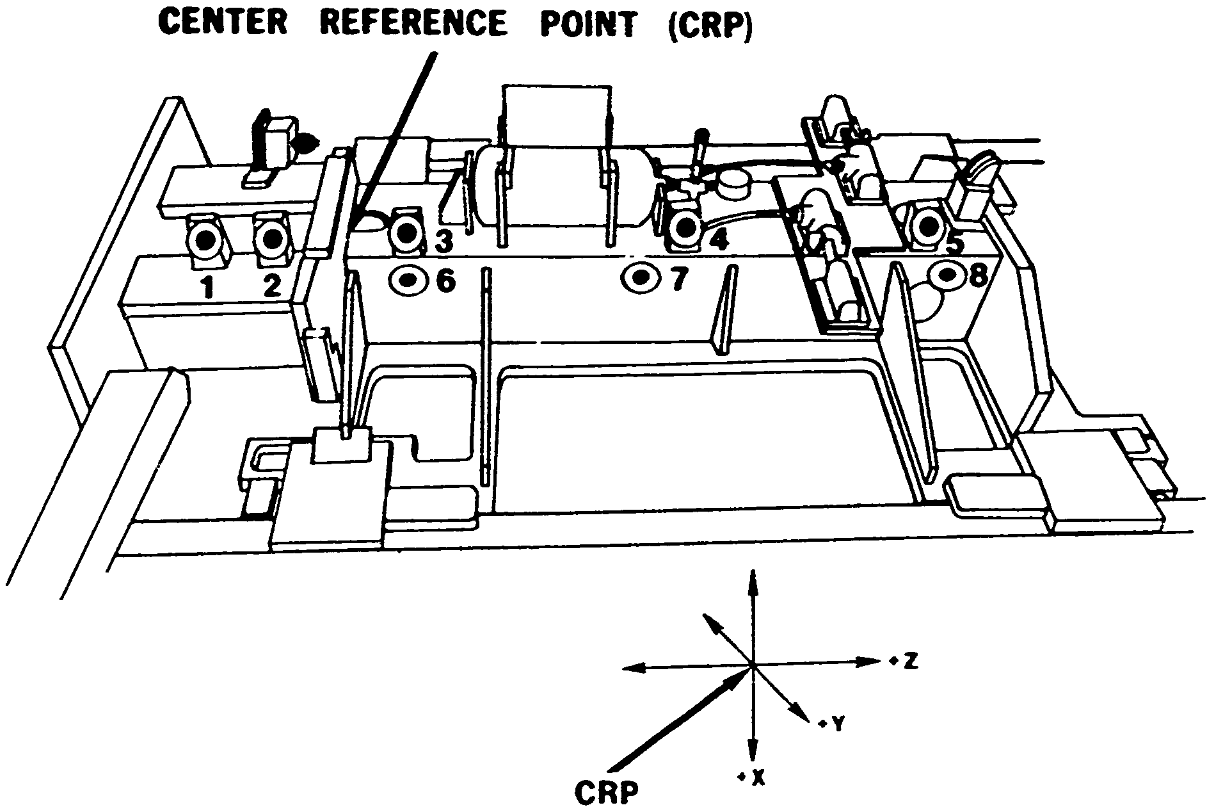


FIGURE A-12: PAYLOAD SLED VELOCITY WHEEL



FIDUCIAL DESCRIPTION AND LOCATION

DESCRIPTION	DIMENSIONS IN FEET		
Target No.	x	y	z
1	-0.46063	0.32283	-0.61385
2	-0.46391	0.33399	-0.22638
3	-0.50197	0.33399	0.55512
4	-0.50032	0.33530	2.17126
5	-0.49869	0.33661	3.61877
6	-0.20177	0.37369	0.56102
7	-0.19751	0.37369	1.90289

Targets	Distance (ft.)
1-2	0.38747
2-3	0.78150
3-4	1.61614
4-5	1.44226
6-7	1.33235

All dimensions are referenced to the Center Reference Point (CRP). The Center Reference Point is located at the attachment point of the Carrier Sled Load Cell.

FIGURE A-13: FIDUCIAL TARGET LOCATIONS

ACES2HDCOA
PAGE
1 OF 1

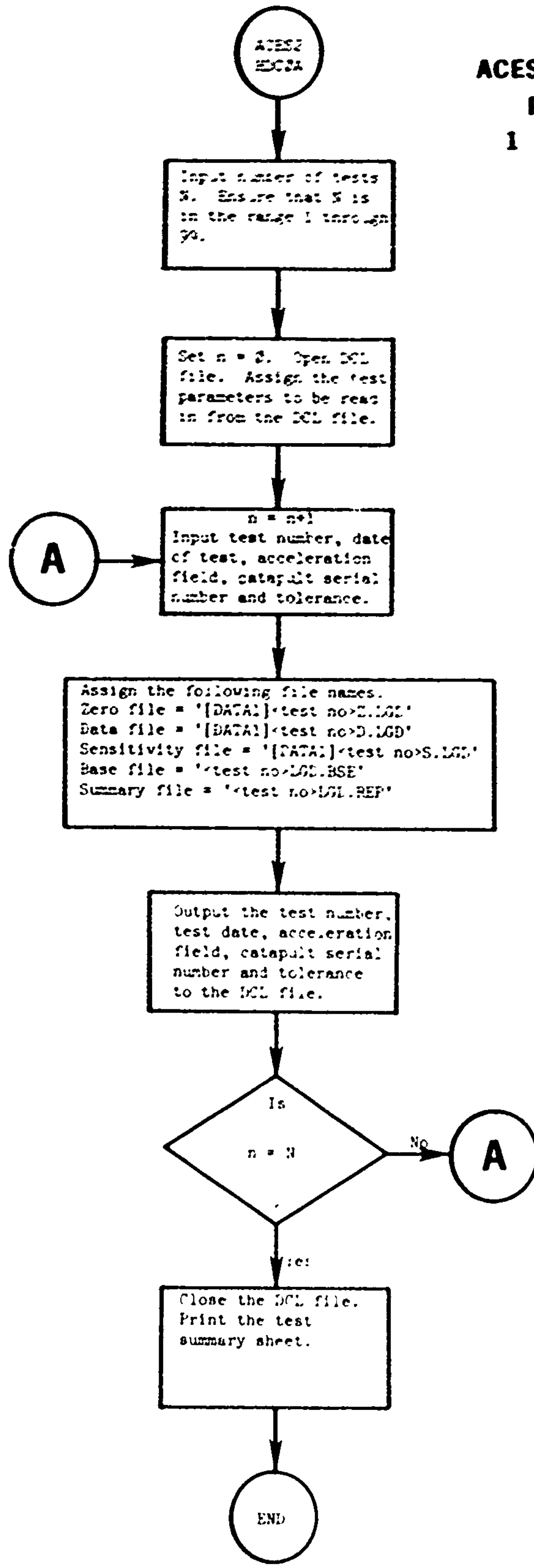


FIGURE A-14: PROGRAM ACES2HDC0A FLOWCHART

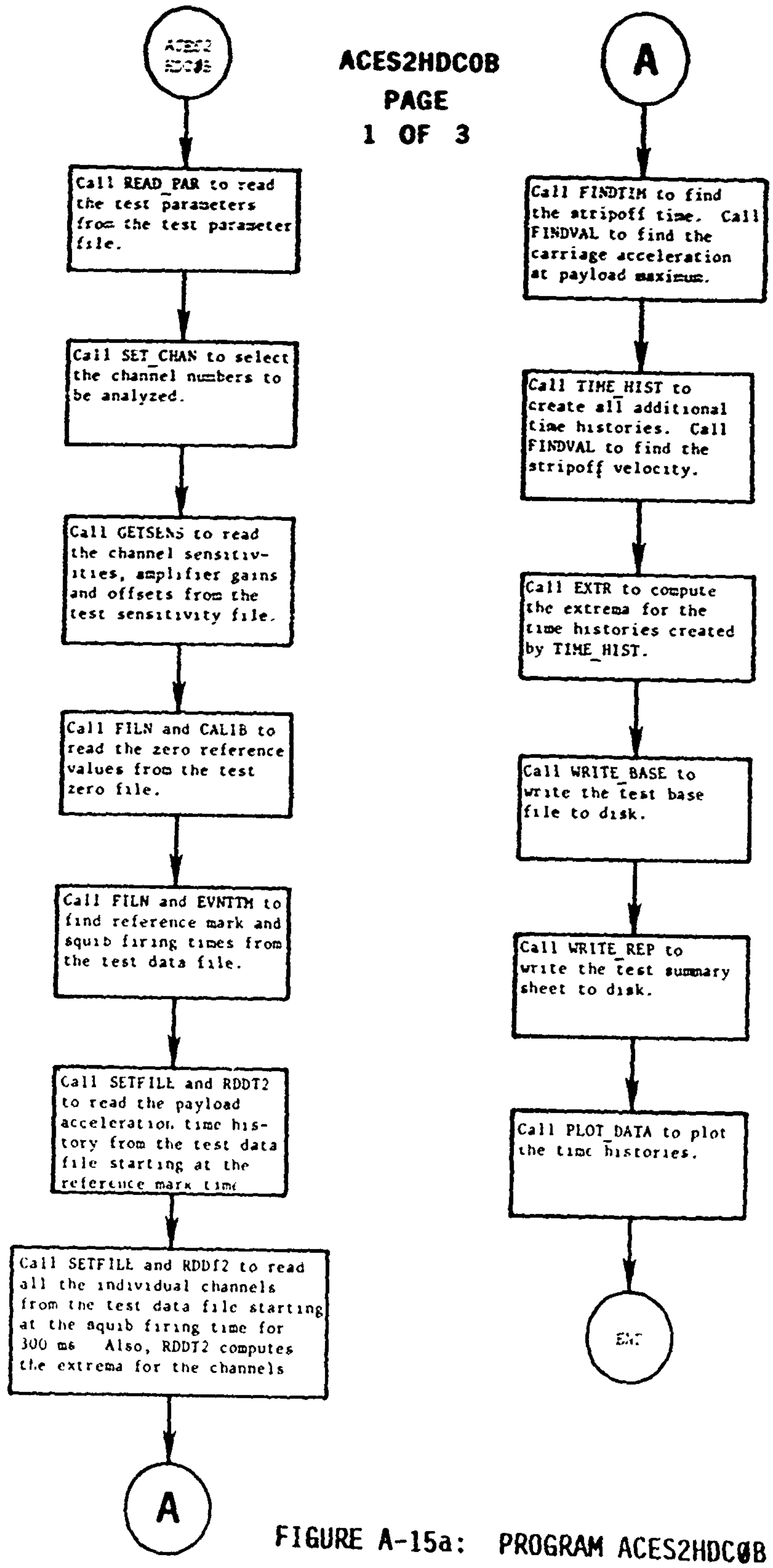


FIGURE A-15a: PROGRAM ACES2HDCØB FLOWCHART

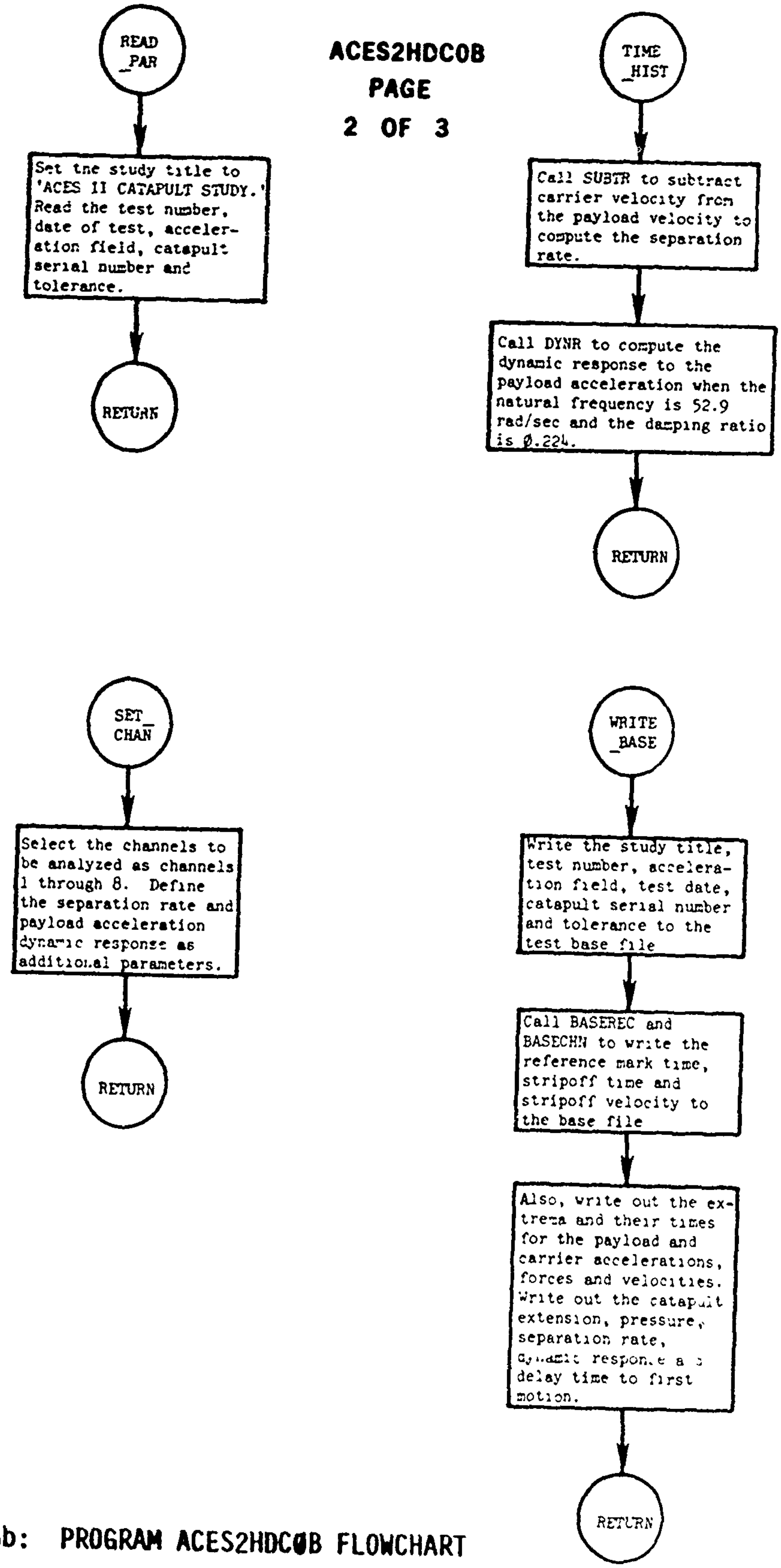


FIGURE A-15b: PROGRAM ACES2HDCØB FLOWCHART

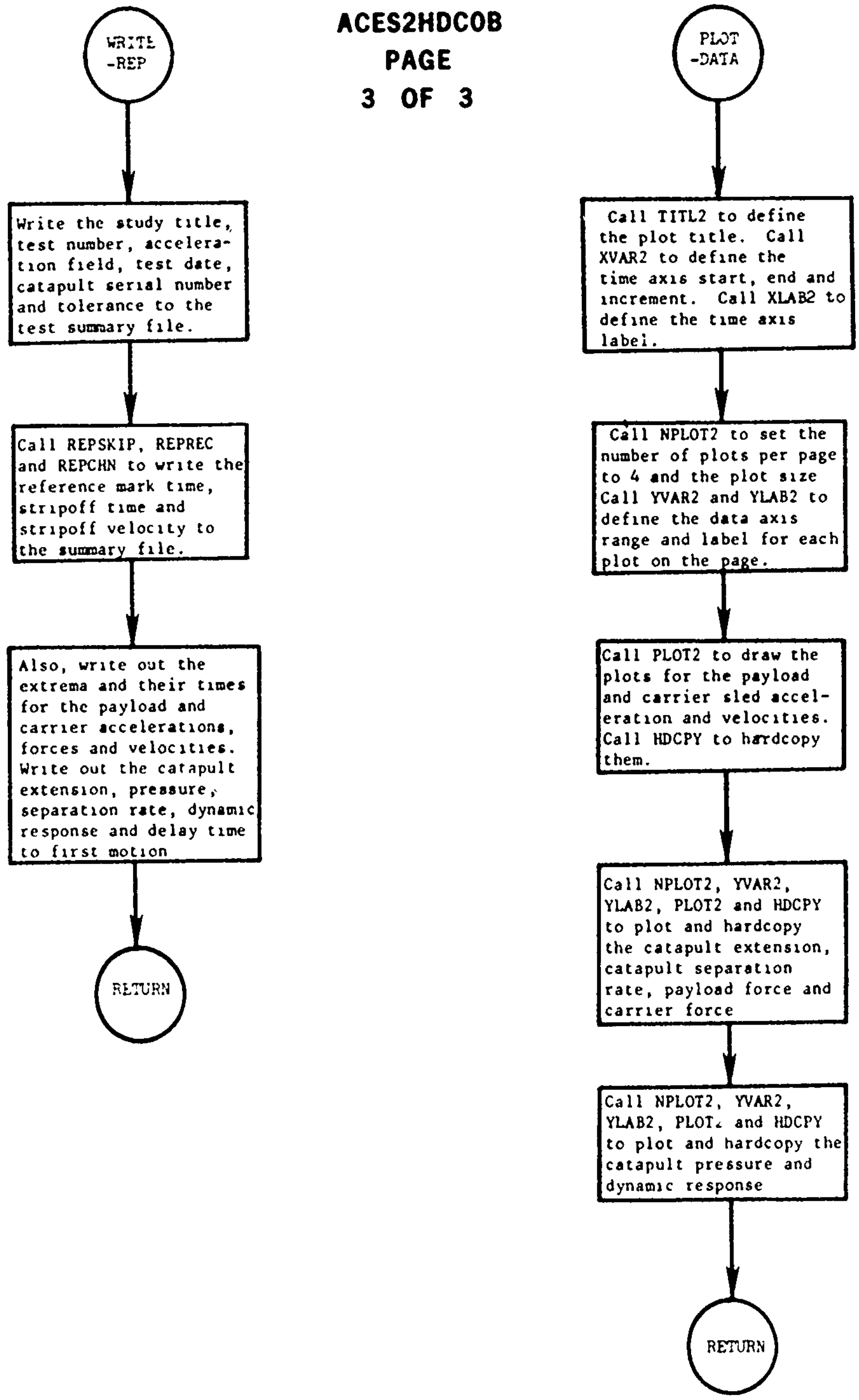


FIGURE A-15c: PROGRAM ACES2HDCØB FLOWCHART

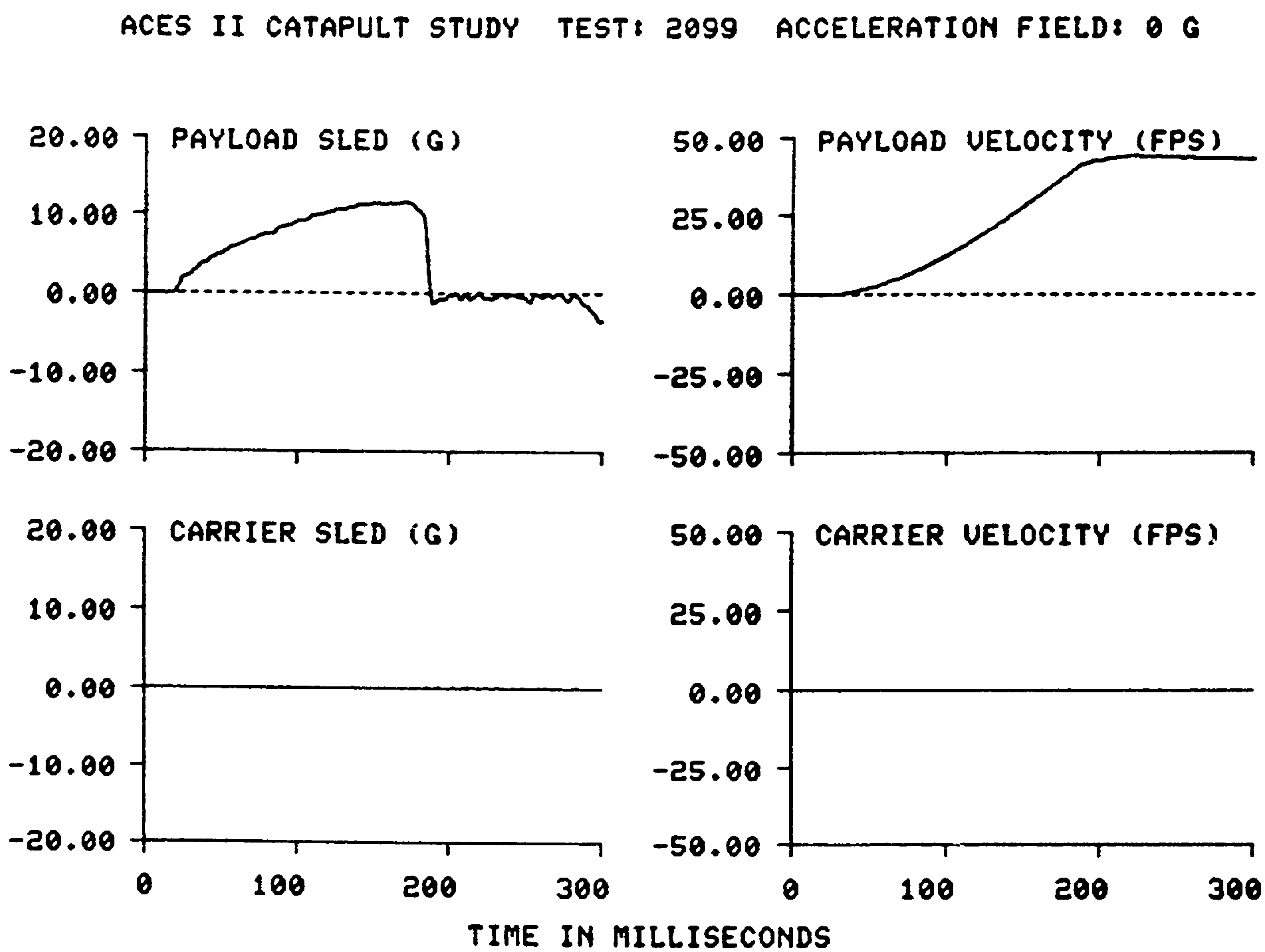
APPENDIX B

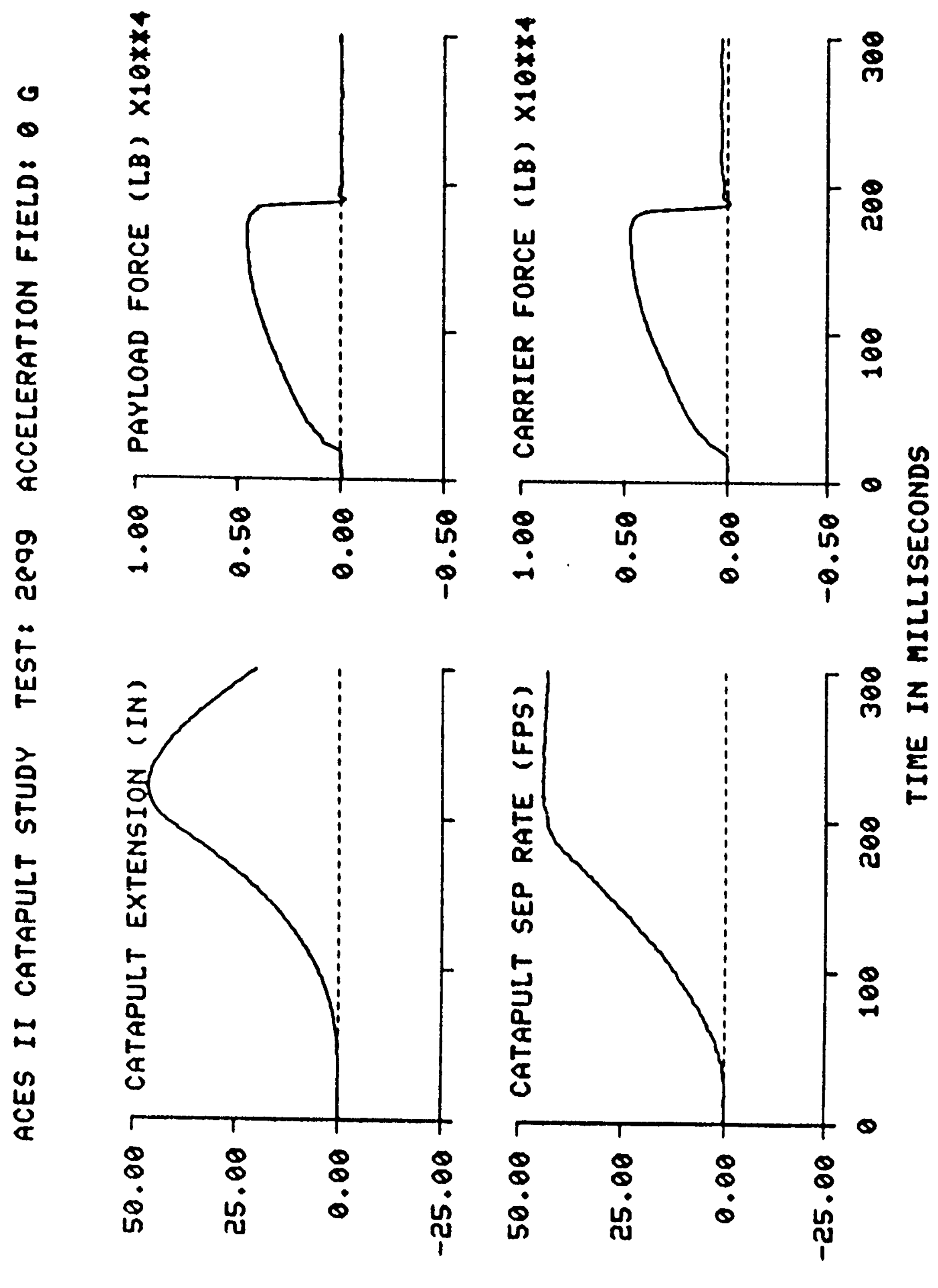
SUMMARIES OF PLOTS OF ELECTRONIC TEST DATA

This appendix contains tables that list the maximum and minimum values with times of occurrence of the forces, accelerations, velocities, displacements, and pressures measured during each catapult test. Also presented in the tables are maximum and minimum values of computes velocities and the Dynamic Response Index. Included in this appendix are data plots of the measured and computed data values. The experimental results will be recorded within a permanent data bank at Armstrong Laboratory.

ACES II CATAPULT STUDY TEST. 2099 ACCELERATION FIELD: 0 G 871119
CATAPULT· CKU-5/A SERIAL #. 10 TOLERANCE MIN

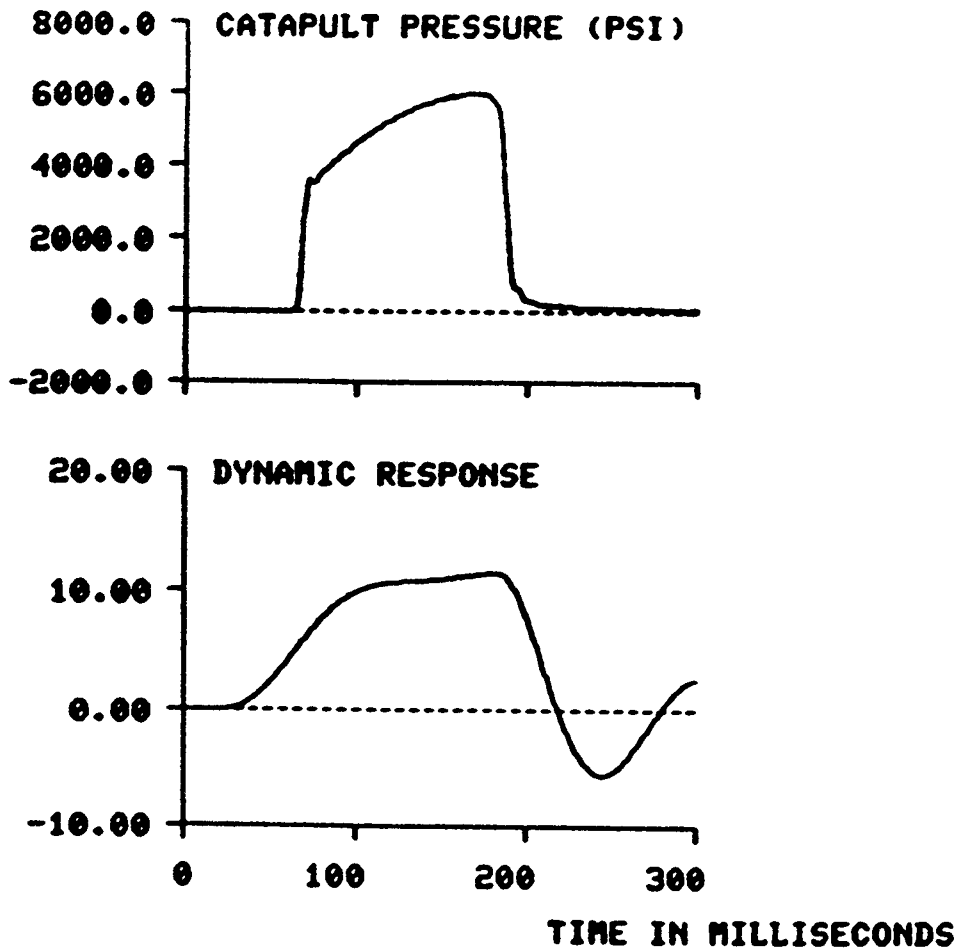
PARAMETER	MAXIMUM VALUE	MINIMUM VALUE	TIME OF MAXIMUM (MS)	TIME OF MINIMUM (MS)
REFERENCE MARK TIME (MS)			-12.	
STRIPOFF TIME (MS)			185.	
PAYLOAD SLED ACCEL (G)	11.63	-3.47	171.	299.
CARRIER ACCEL @ PAYLOAD MAX (G)	0.00	-0.06	171.	9.
PAYLOAD FORCE (LB)	4543.25	-204.41	157.	189.
CARRIER FORCE (LB)	4722.30	-125.97	161.	189.
CATAPULT EXTENSION (INCHES)	46.53	-0.07	219.	2.
CATAPULT SEPARATION RATE (FPS)	44.44	-0.29	217.	19.
CATAPULT PRESSURE (PSI)	6008.84	-36.98	164.	0.
PAYLOAD VELOCITY (FPS)	44.24	-0.24	217.	19.
CARRIER VELOCITY (FPS)	0.05	-0.20	0.	1.
STRIPOFF VELOCITY (FPS)	40.69		185.	
DYNAMIC RESPONSE INDEX	11.56	-5.61	183.	245.
DELAY TIME TO FIRST MOTION (MS)			44.	


ACES II CATAPULT STUDY TEST: 2099 ACCELERATION FIELD: 0 G
PAYLOAD SLED (G)
PAYLOAD VELOCITY (FPS)
CARRIER SLED (G)
CARRIER VELOCITY (FPS)
20.00
10.00
0.00
-10.00
-20.00
50.00
25.00
0.00
-25.00
-50.00
0
100
200
300
TIME IN MILLISECONDS



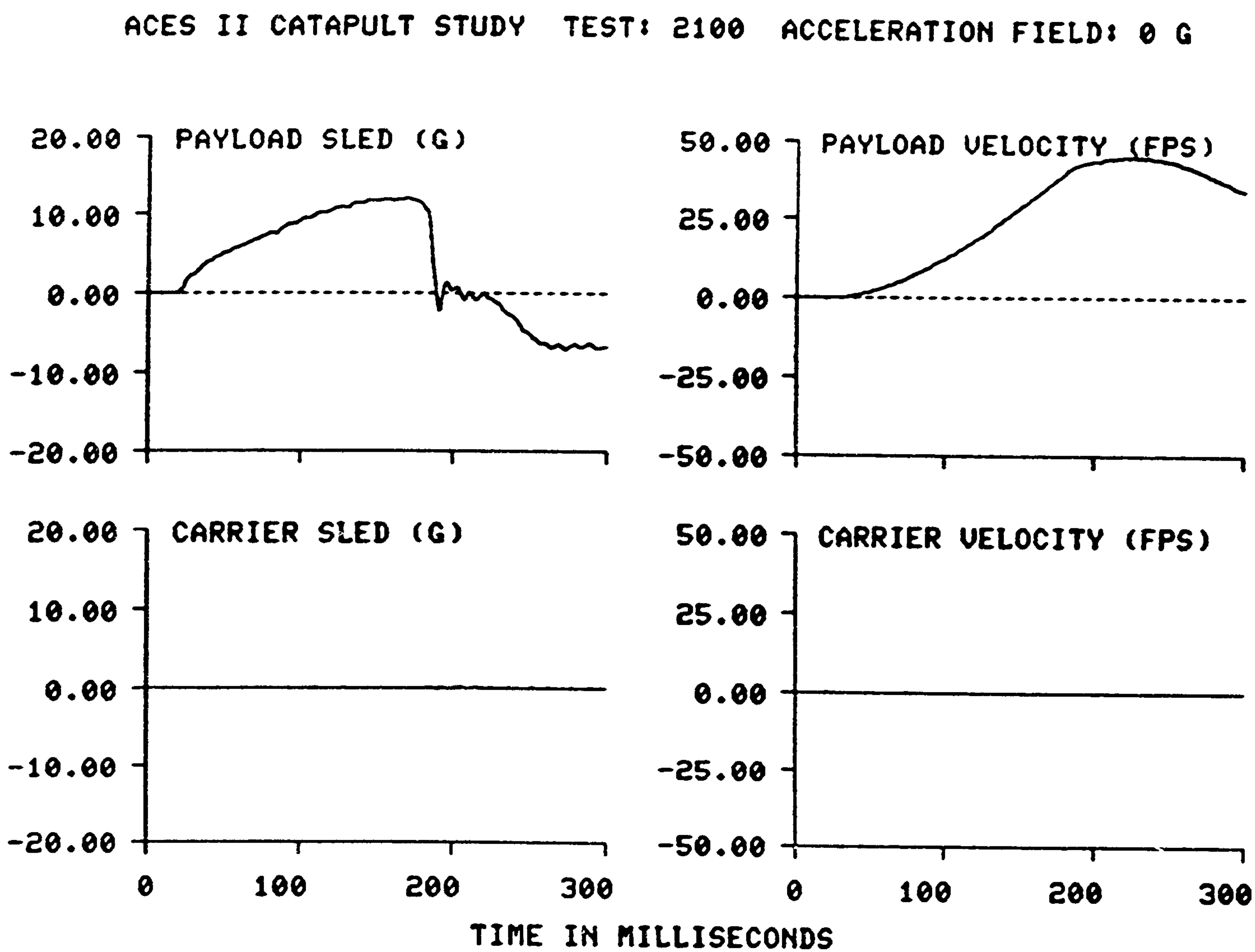
ACES II CATAPULT STUDY TEST: 2099 ACCELERATION FIELD: 0 G
CATAPULT EXTENSION (IN)
PAYLOAD FORCE (LB) X10**4
CATAPULT SEP RATE (FPS)
CARRIER FORCE (LB) X10**4
50.00
25.00
0.00
-25.00
1.00
0.50
0.00
-0.50
0
100
200
300
TIME IN MILLISECONDS

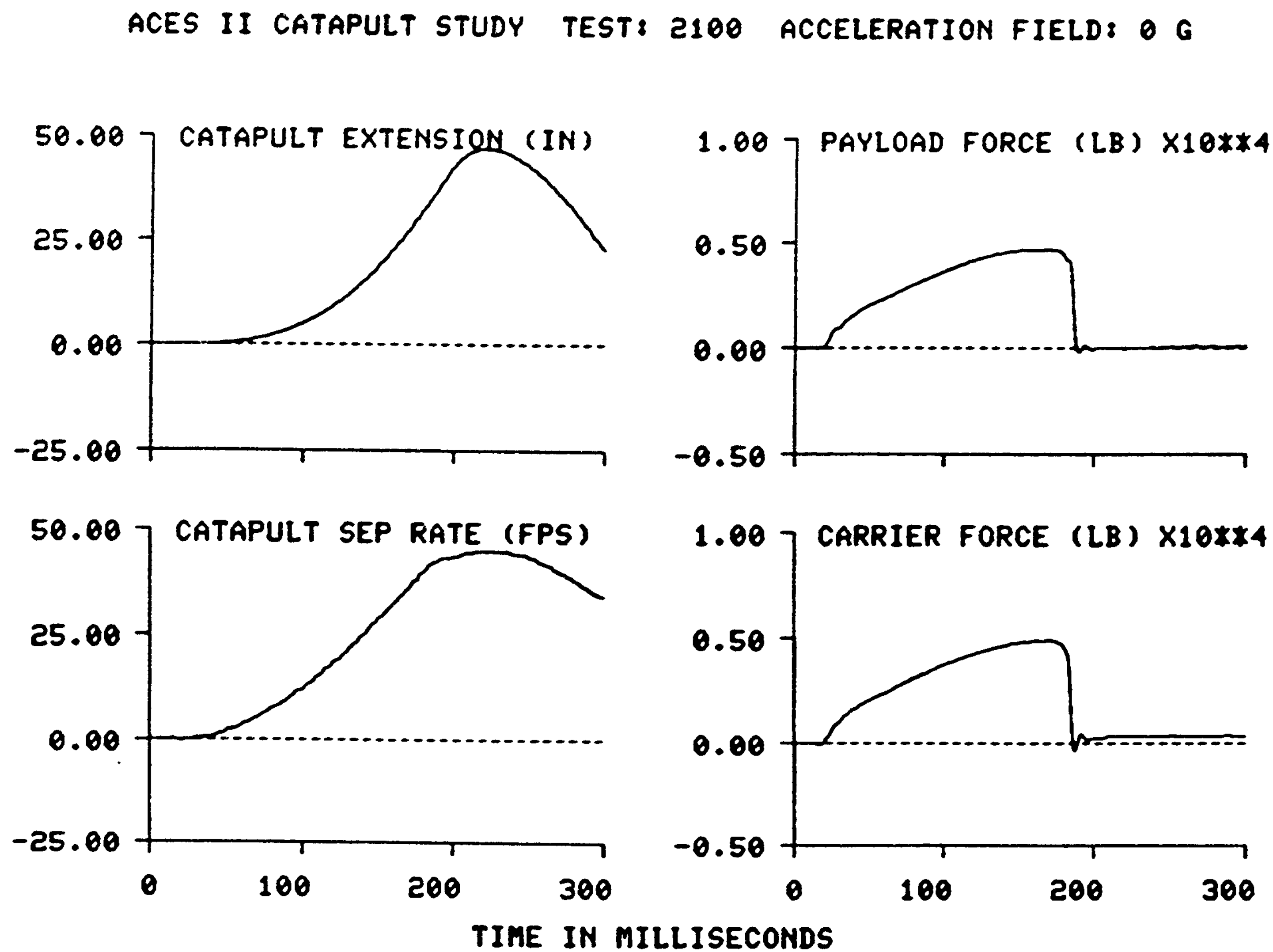
ACES II CATAPULT STUDY TEST: 2099 ACCELERATION FIELD: 0 G



ACES II CATAPULT STUDY TEST: 2100 ACCELERATION FIELD: 0 G 871119
CATAPULT: CKU-5/A SERIAL #: 2 TOLERANCE: MAX

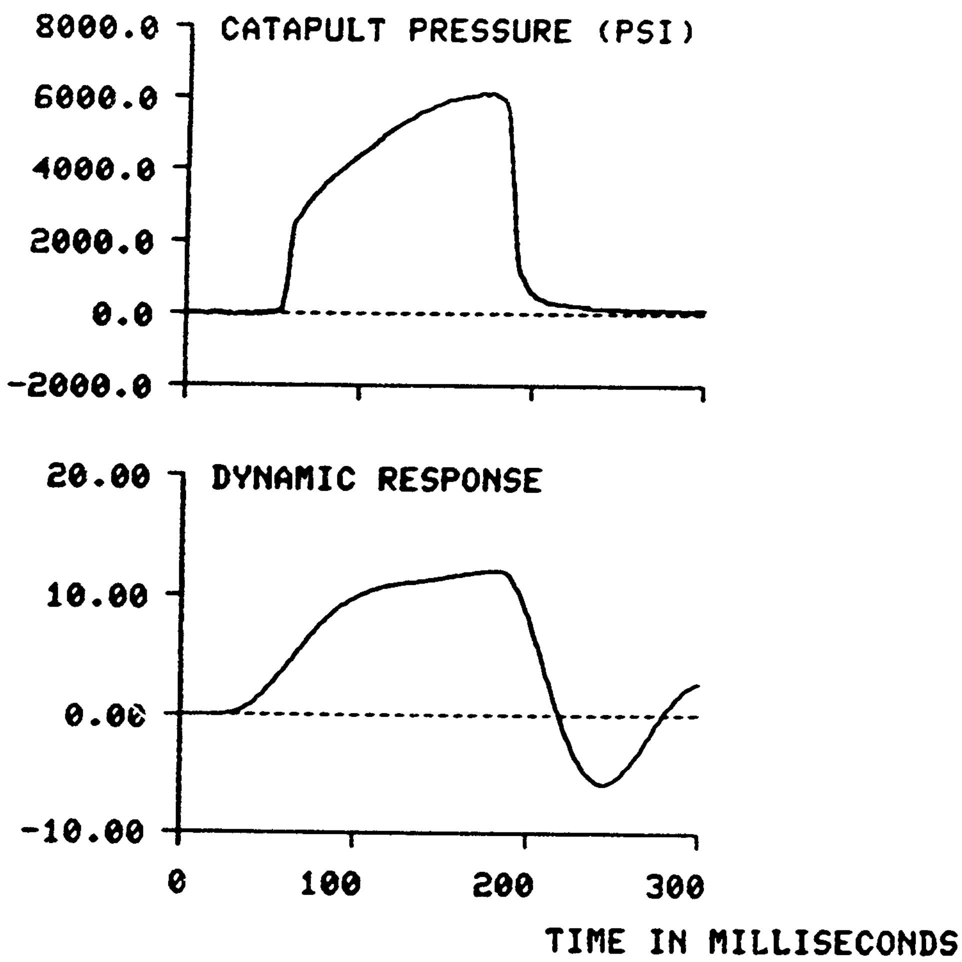
PARAMETER	MAXIMUM VALUE	MINIMUM VALUE	TIME OF MAXIMUM (MS)	TIME OF MINIMUM (MS)
REFERENCE MARK TIME (MS)			-12.	
STRIPOFF TIME (MS)			185.	
PAYLOAD SLED ACCEL (G)	11.97	-7.02	169.	272.
CARRIER ACCEL @ PAYLOAD MAX (G)	0.00	-0.13	169.	191.
PAYLOAD FORCE (LB)	4702.18	-145.44	167.	190.
CARRIER FORCE (LB)	4947.22	-350.89	170.	188.
CATAPULT EXTENSION (INCHES)	47.10	-0.01	221.	C.
CATAPULT SEPARATION RATE (FPS)	45.21	-0.27	227.	21.
CATAPULT PRESSURE (PSI)	6118.75	-27.00	168.	3.
PAYLOAD VELOCITY (FPS)	44.98	-0.26	219.	21.
CARRIER VELOCITY (FPS)	0.26	-0.23	22.	0.
STRIPOFF VELOCITY (FPS)	41.71		185.	
DYNAMIC RESPONSE INDEX	12.06	-5.85	182.	245.
DELAY TIME TO FIRST MOTION (MS)			41.	


ACES II CATAPULT STUDY TEST: 2100 ACCELERATION FIELD: 0 G
PAYLOAD SLED (G)
20.00
10.00
0.00
-10.00
-20.00
PAYLOAD VELOCITY (FPS)
50.00
25.00
0.00
-25.00
-50.00
CARRIER SLED (G)
20.00
10.00
0.00
-10.00
-20.00
CARRIER VELOCITY (FPS)
50.00
25.00
0.00
-25.00
-50.00
0
100
200
300
0
100
200
300
TIME IN MILLISECONDS



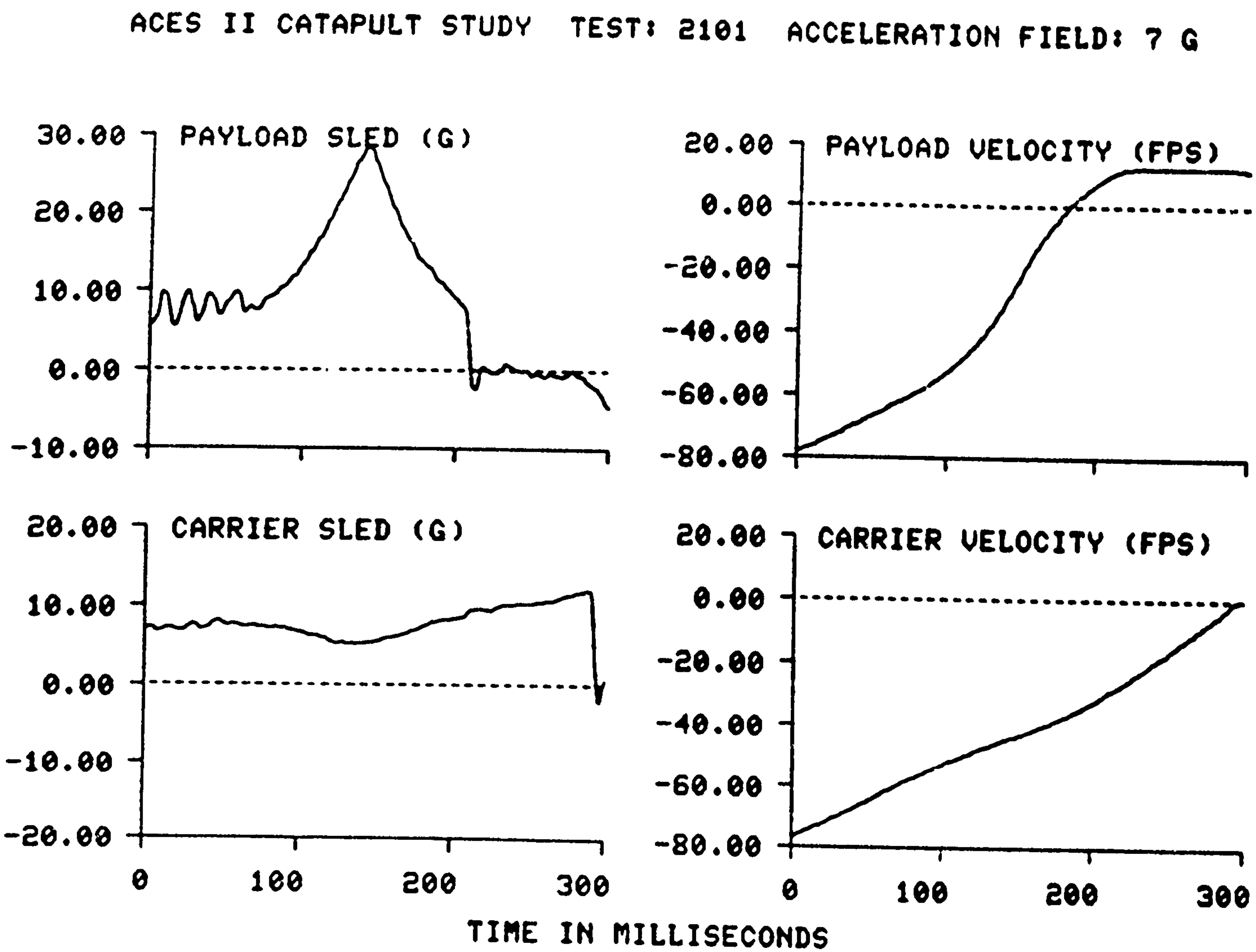
ACES II CATAPULT STUDY TEST: 2100 ACCELERATION FIELD: 0 G
CATAPULT EXTENSION (IN)
PAYLOAD FORCE (LB) X10**4
CATAPULT SEP RATE (FPS)
CARRIER FORCE (LB) X10**4
50.00
25.00
0.00
-25.00
1.00
0.50
0.00
-0.50
0
100
200
300
TIME IN MILLISECONDS

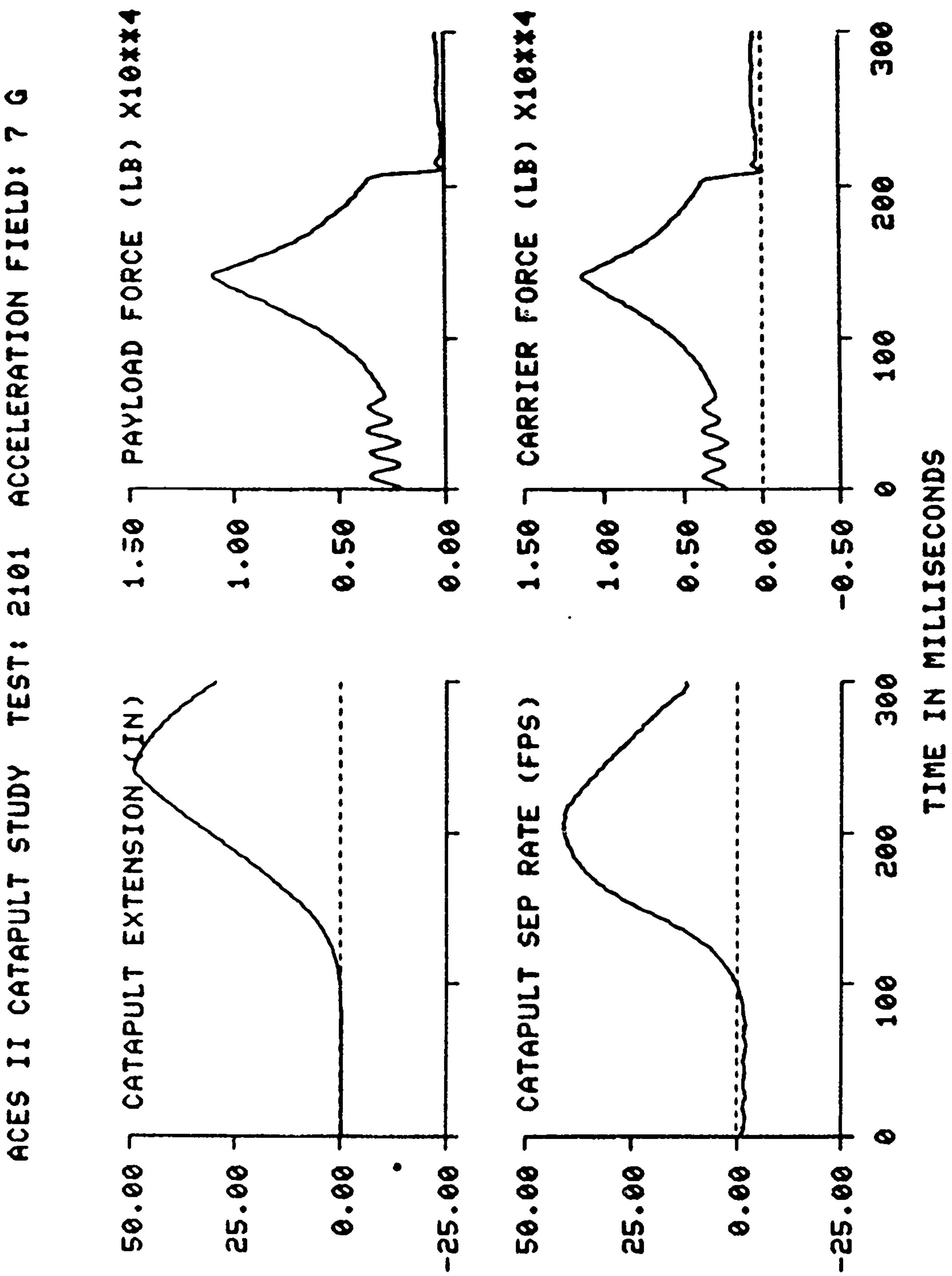
ACES II CATAPULT STUDY TEST: 2100 ACCELERATION FIELD: 0 G



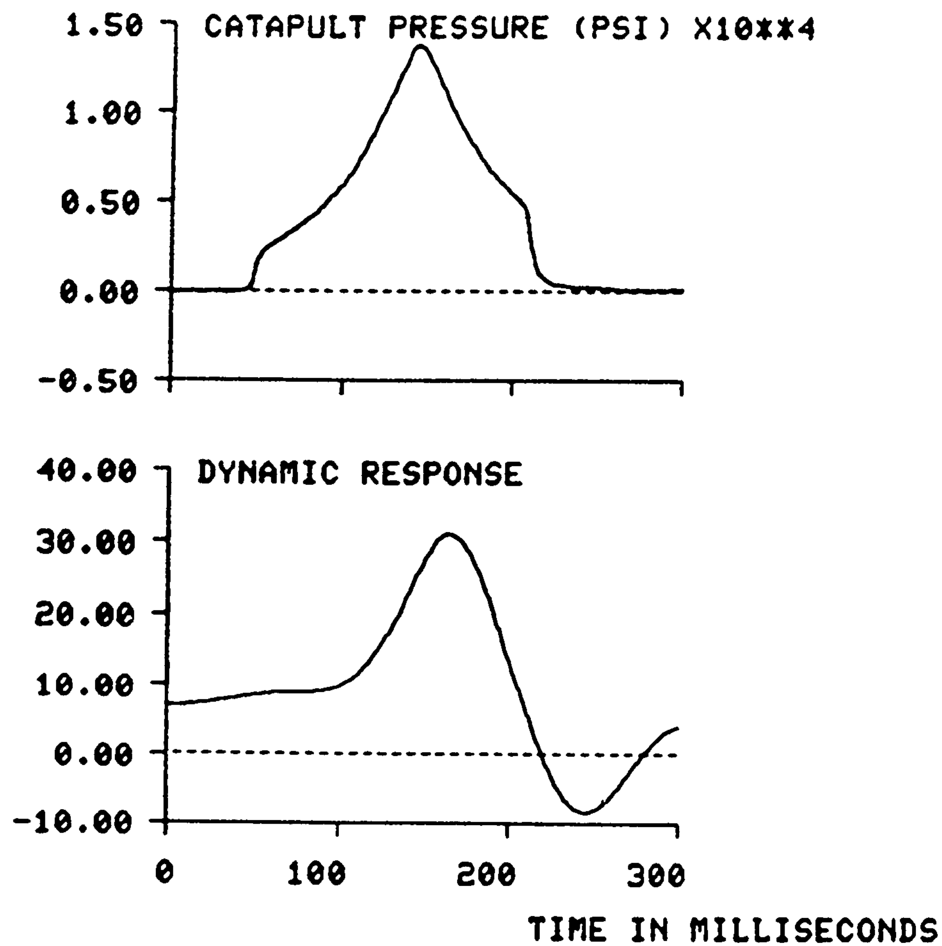
ACES II CATAPULT STUDY TEST: 2101 ACCELERATION FIELD: 7 G 871120
CATAPULT: CKU-5/A SERIAL #: 9 TOLERANCE: MIN

PARAMETER	MAXIMUM VALUE	MINIMUM VALUE	TIME OF MAXIMUM (MS)	TIME OF MINIMUM (MS)
REFERENCE M. . TIME (MS)			-180.	
STRIPOFF TI... (MS)			208.	
PAYLOAD SLED ACCEL (G)	28.53	-4.56	141.	300.
CARRIER ACCEL @ PAYLOAD MAX (G)	5.21	-2.04	141.	297.
PAYLOAD FORCE (LB)	10988.58	93.94	141.	231.
CARRIER FORCE (LB)	11339.94	-80.97	141.	210.
CATAPULT EXTENSION (INCHES)	49.10	-0.25	241.	30.
CATAPULT SEPARATION RATE (FPS)	41.10	-2.13	206.	60.
CATAPULT PRESSURE (PSI)	13803.45	-36.98	143.	0.
PAYLOAD VELOCITY (FPS)	13.25	-78.21	229.	0.
CARRIER VELOCITY (FPS)	0.13	-77.08	298.	0.
STRIPOFF VELOCITY (FPS)	40.85		208.	
DYNAMIC RESPONSE INDEX	30.93	-8.53	165.	246.
DELAY TIME TO FIRST MOTION (MS)			92.	


ACES II CATAPULT STUDY TEST: 2101 ACCELERATION FIELD: 7 G
PAYLOAD SLED (G)
30.00
20.00
10.00
0.00
-10.00
PAYLOAD VELOCITY (FPS)
20.00
0.00
-20.00
-40.00
-60.00
-80.00
CARRIER SLED (G)
20.00
10.00
0.00
-10.00
-20.00
CARRIER VELOCITY (FPS)
20.00
0.00
-20.00
-40.00
-60.00
-80.00
0
100
200
300
0
100
200
300
TIME IN MILLISECONDS


ACES II CATAPULT STUDY TEST: 2101 ACCELERATION FIELD: 7 G
CATAPULT EXTENSION (IN)
50.00
25.00
0.00
-25.00
PAYLOAD FORCE (LB) X10**4
1.50
1.00
0.50
0.00
CATAPULT SEP RATE (FPS)
50.00
25.00
0.00
-25.00
CARRIER FORCE (LB) X10**4
1.50
1.00
0.50
0.00
-0.50
0
100
200
300
TIME IN MILLISECONDS

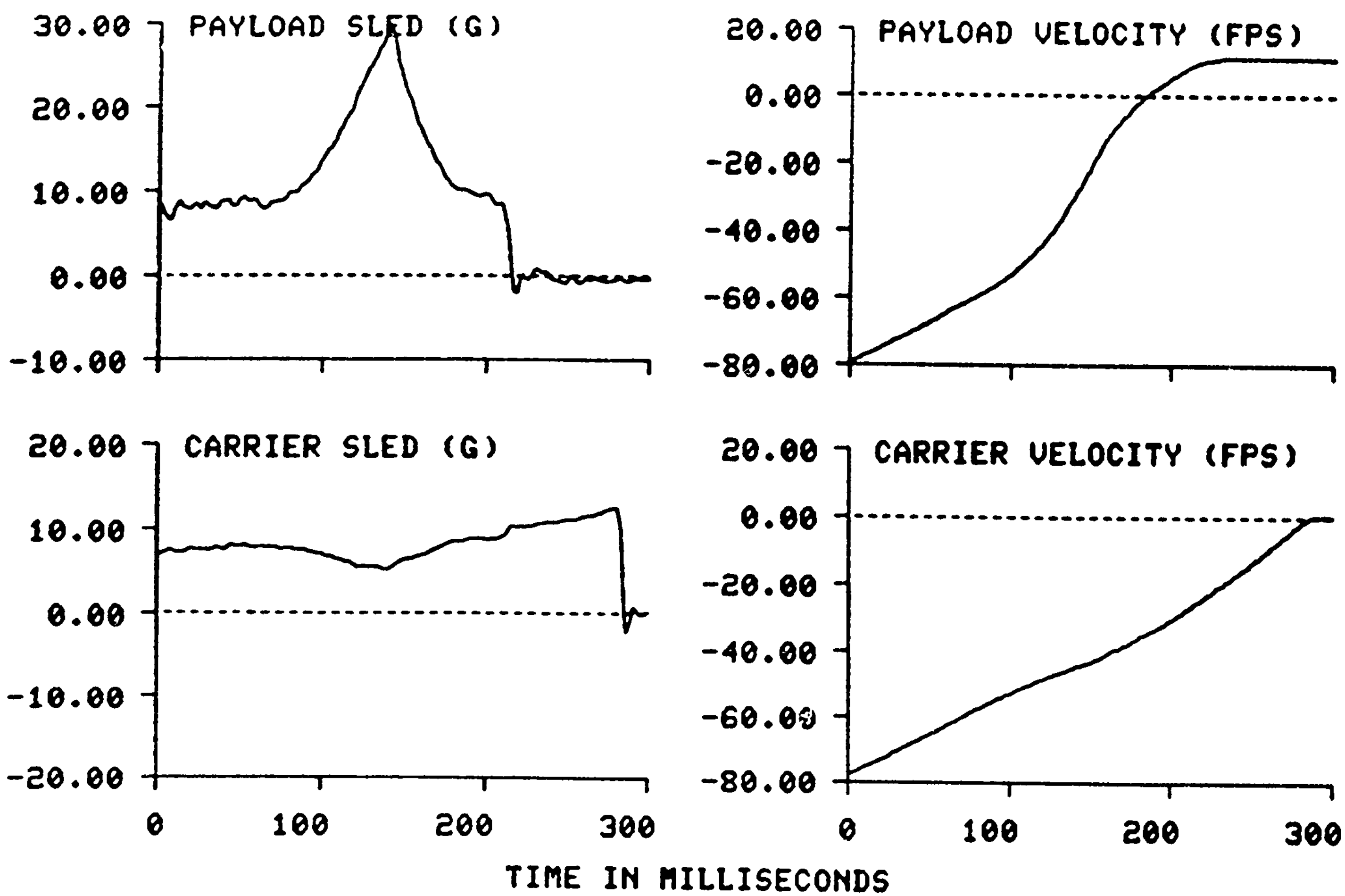
ACES II CATAPULT STUDY TEST: 2101 ACCELERATION FIELD: 7 G

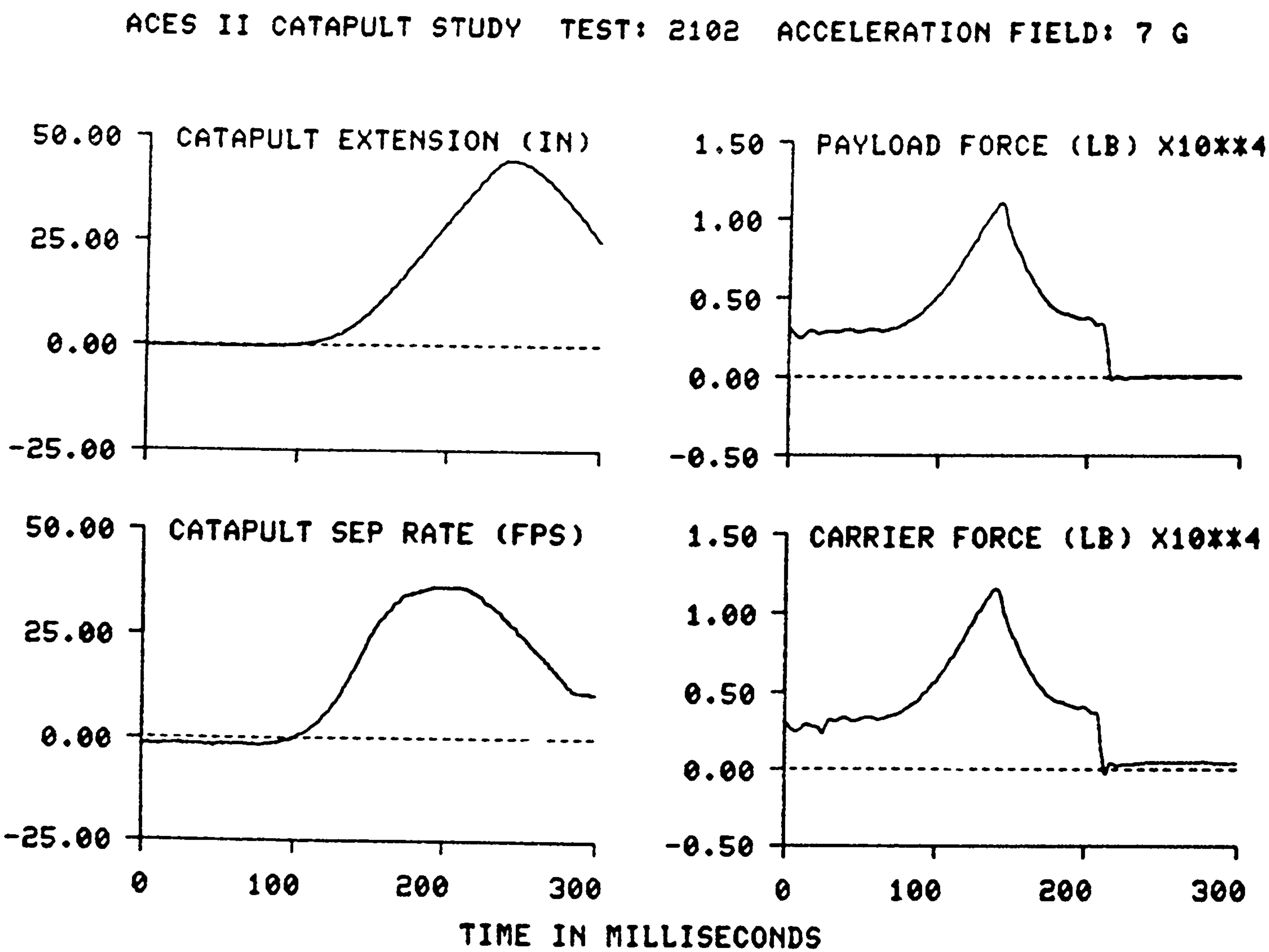


ACES II CATAPULT STUDY TEST: 2102 ACCELERATION FIELD: 7 G 871120
CATAPULT· CKU-5/A SERIAL #: 3 TOLERANCE: MAX

PARAMETER	MAXIMUM VALUE	MINIMUM VALUE	TIME OF MAXIMUM (MS)	TIME OF MINIMUM (MS)
REFERENCE MARK TIME (MS)			-180.	
STRIPOFF TIME (MS)			212.	
PAYLOAD SLED ACCEL (G)	29.31	-1.99	141.	218.
CARRIER ACCEL @ PAYLOAD MAX (G)	5.26	-2.24	141.	287.
PAYLOAD FORCE (LB)	11042.08	-177.40	141.	216.
CARRIER FORCE (LB)	11504.39	-366.37	140.	214.
CATAPULT EXTENSION (INCHES)	44.32	-0.16	239.	1.
CATAPULT SEPARATION RATE (FPS)	36.26	-1.97	196.	47.
CATAPULT PRESSURE (PSI)	14351.06	-38.98	143.	2.
PAYLOAD VELOCITY (FPS)	11.74	-79.22	234.	0.
CARRIER VELOCITY (FPS)	0.47	-77.75	295.	0.
STRIPOFF VELOCITY (FPS)	36.01		212.	
DYNAMIC RESPONSE INDEX	30.64	-5.91	162.	244.
DELAY TIME TO FIRST MOTION (MS)			92.	

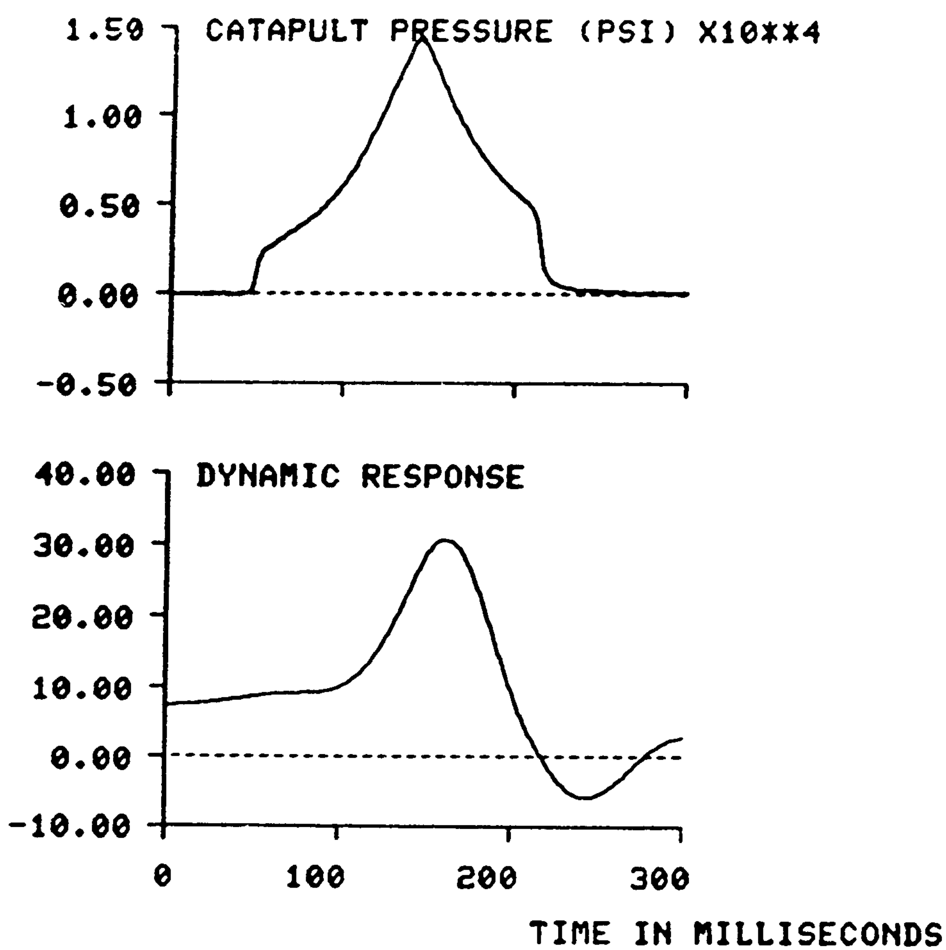
ACES II CATAPULT STUDY TEST: 2102 ACCELERATION FIELD: 7 G





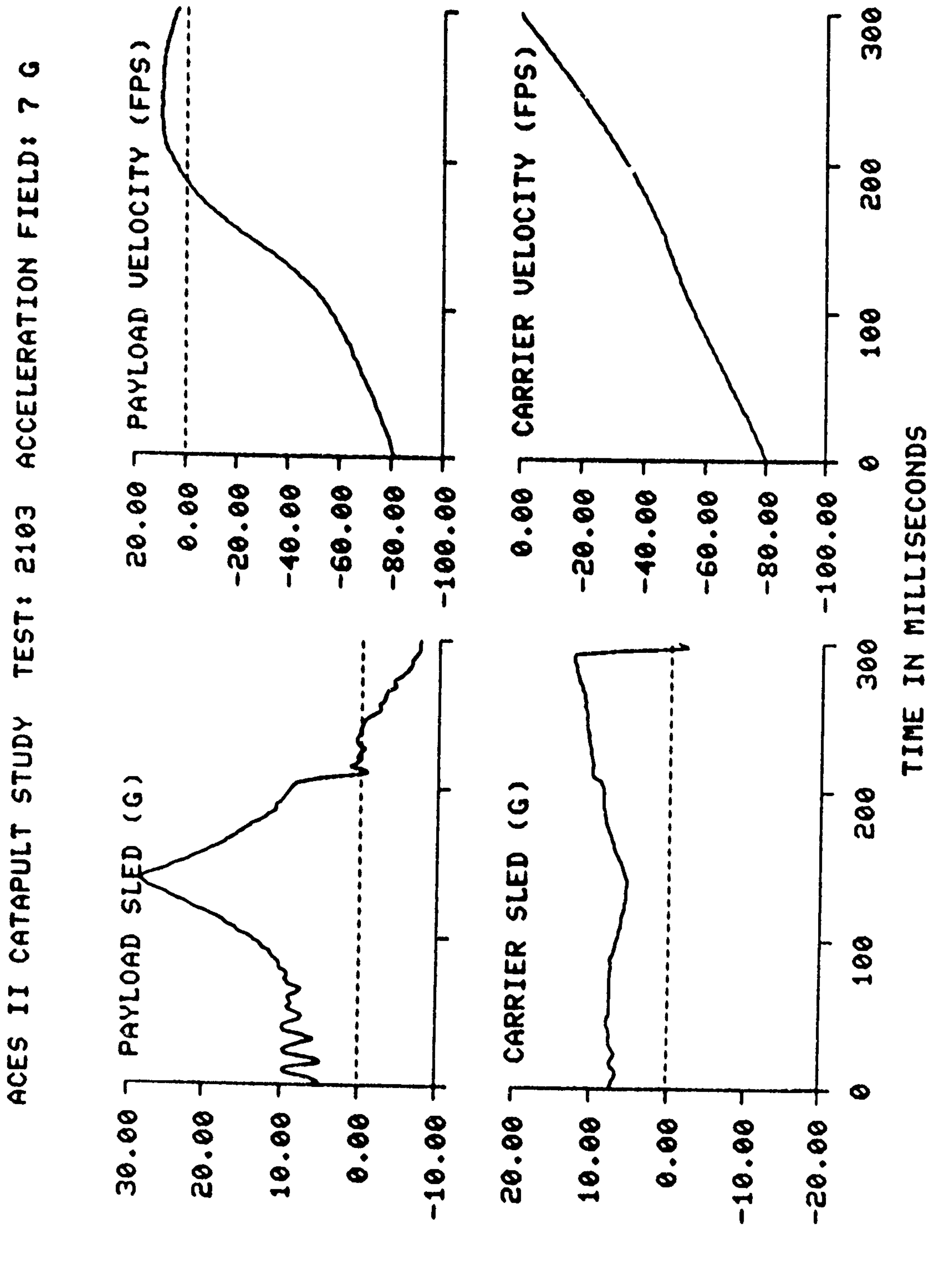
ACES II CATAPULT STUDY TEST: 2102 ACCELERATION FIELD: 7 G
CATAPULT EXTENSION (IN)
50.00
25.00
0.00
-25.00
PAYLOAD FORCE (LB) X10**4
1.50
1.00
0.50
0.00
-0.50
CATAPULT SEP RATE (FPS)
50.00
25.00
0.00
-25.00
CARRIER FORCE (LB) X10**4
1.50
1.00
0.50
0.00
-0.50
0
100
200
300
0
100
200
300
TIME IN MILLISECONDS

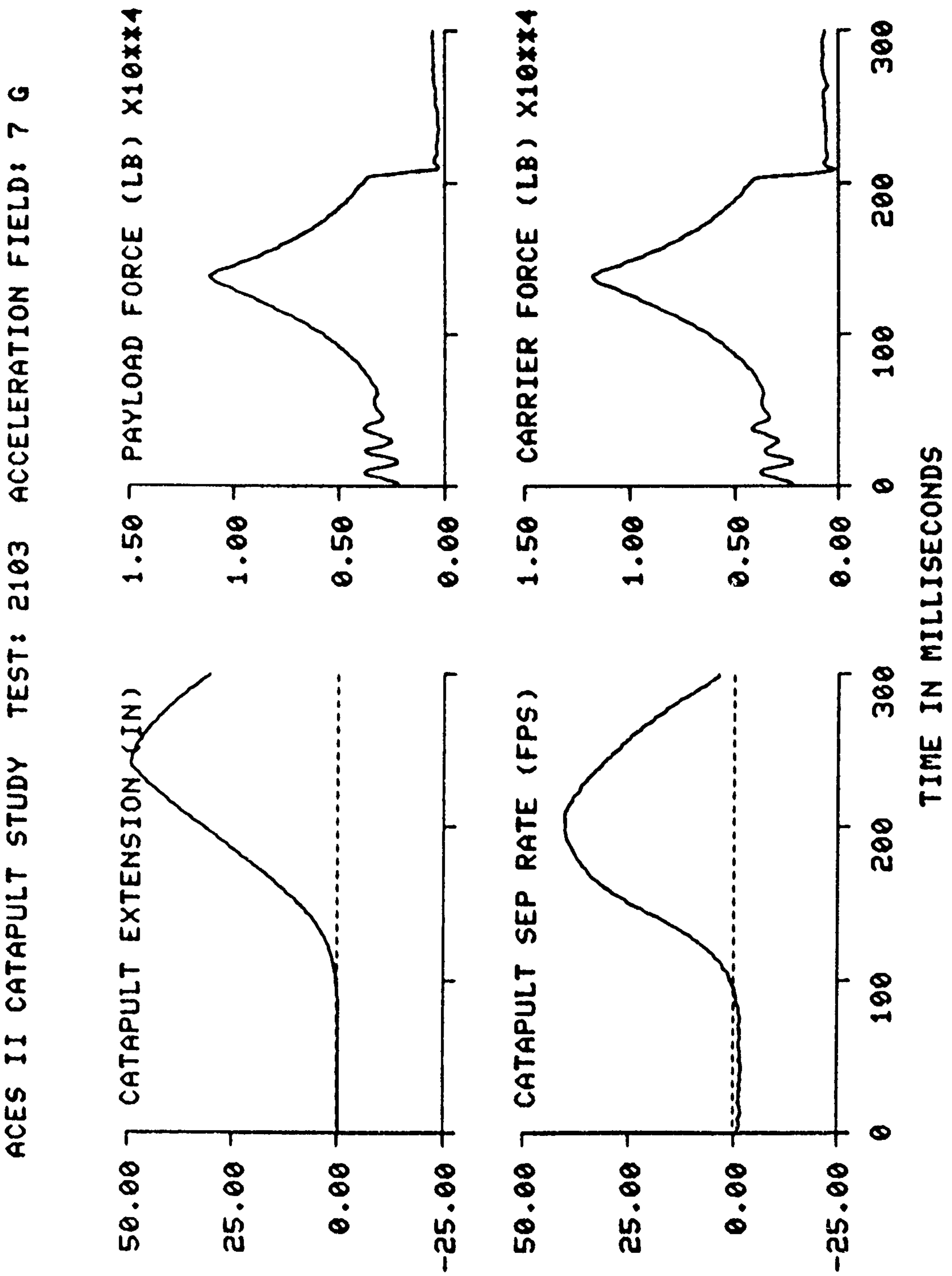
ACES II CATAPULT STUDY TEST: 2102 ACCELERATION FIELD: 7 G



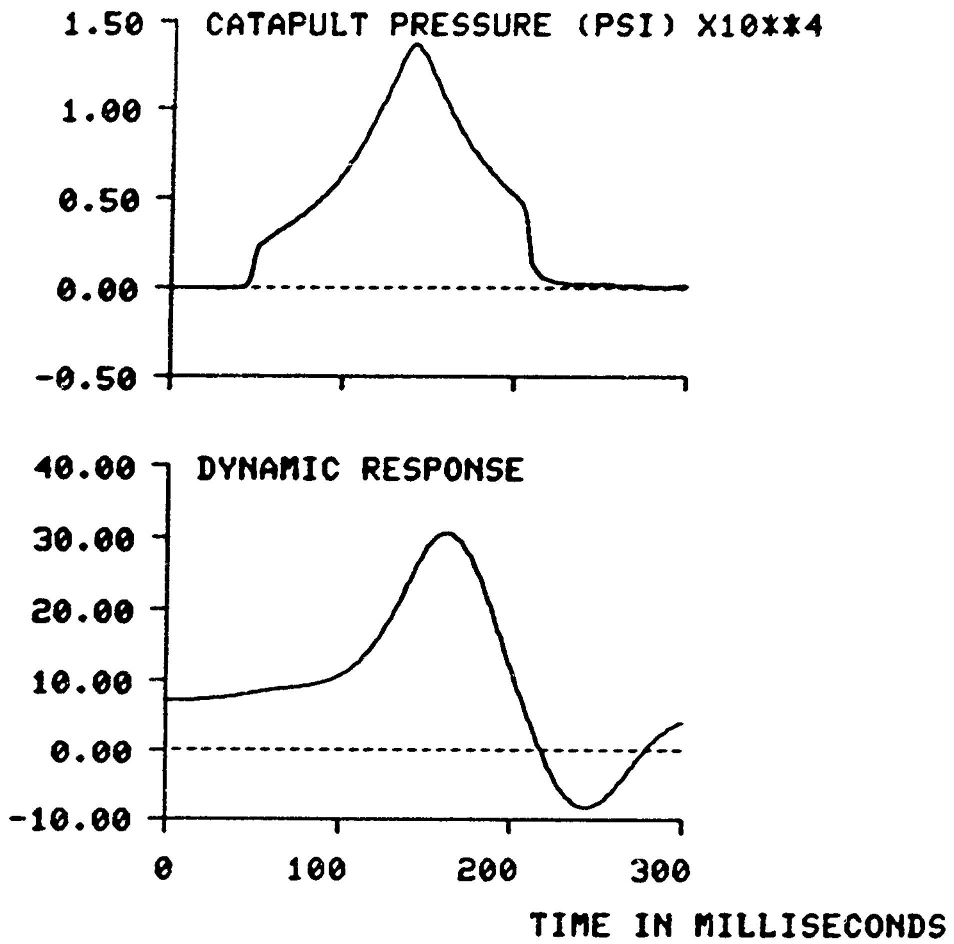
ACES II CATAPULT STUDY TEST: 2103 ACCELERATION FIELD: 7 G 871123
CATAPULT: CKU-5/A SERIAL #: 8 TOLERANCE: MIN

PARAMETER	MAXIMUM VALUE	MINIMUM VALUE	TIME OF MAXIMUM (MS)	TIME OF MINIMUM (MS)
REFERENCE MARK TIME (MS)			-172.	
STRIPOFF TIME (MS)			206.	
PAYLOAD SLED ACCEL (G)	28.49	-7.50	138.	295.
CARRIER ACCEL @ PAYLOAD MAX (G)	5.31	-2.25	138.	298.
PAYLOAD FORCE (LB)	11144.51	274.86	138.	210.
CARRIER FORCE (LB)	11777.29	156.45	138.	209.
CATAPULT EXTENSION (INCHES)	49.39	-0.22	241.	0.
CATAPULT SEPARATION RATE (FPS)	40.30	-1.68	205.	15.
CATAPULT PRESSURE (PSI)	13692.49	-48.00	140.	27.
PAYLOAD VELOCITY (FPS)	9.98	-81.48	227.	0.
CARRIER VELOCITY (FPS)	-0.08	-80.55	299.	0.
STRIPOFF VELOCITY (FPS)	40.05		206.	
DYNAMIC RESPONSE INDEX	30.58	-8.34	163.	244.
DELAY TIME TO FIRST MOTION (MS)			95.	


ACES II CATAPULT STUDY TEST: 2103 ACCELERATION FIELD: 7 G
PAYLOAD SLED (G)
PAYLOAD VELOCITY (FPS)
CARRIER SLED (G)
CARRIER VELOCITY (FPS)
TIME IN MILLISECONDS

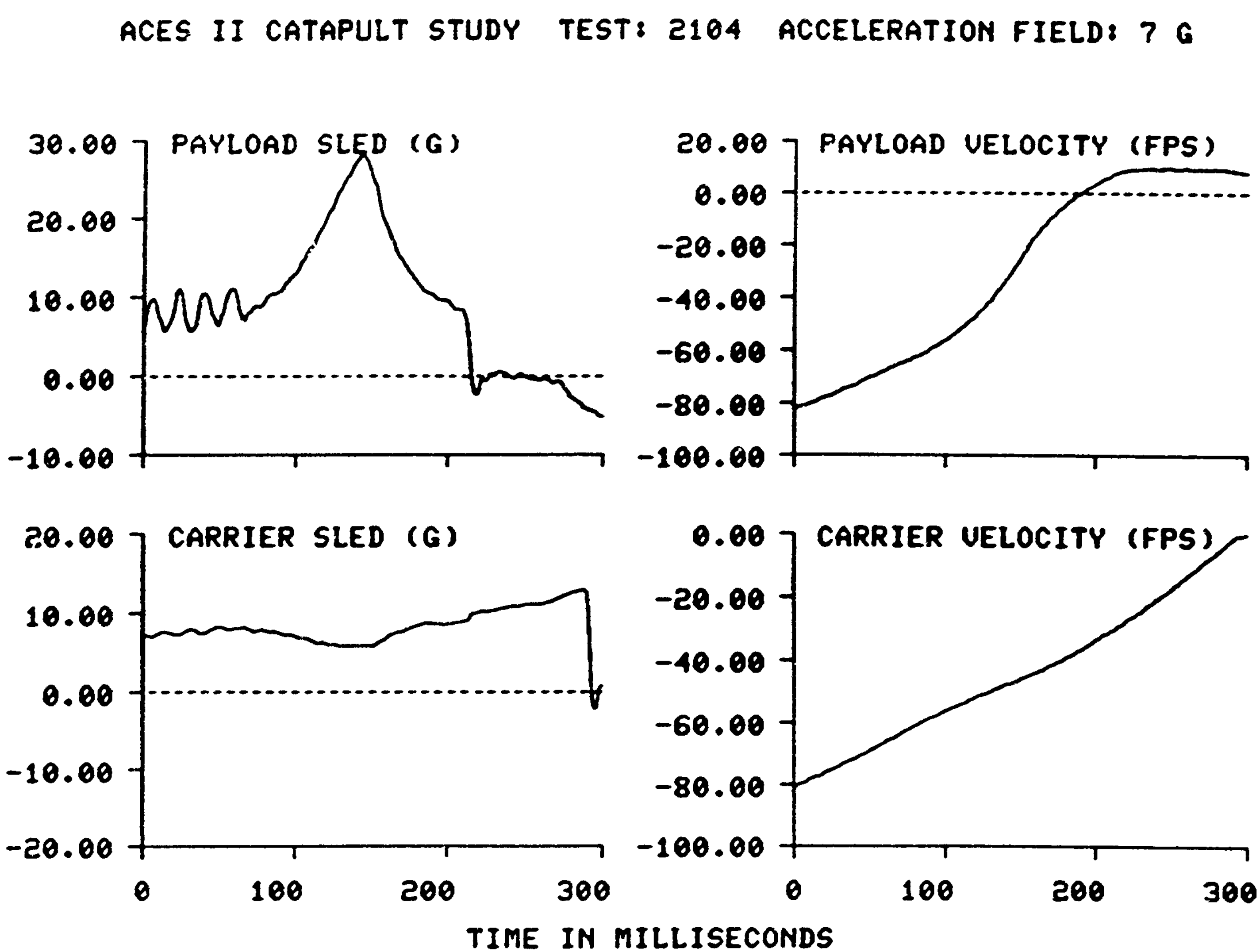

ACES II CATAPULT STUDY TEST: 2103 ACCELERATION FIELD: 7 G
CATAPULT EXTENSION (IN)
PAYLOAD FORCE (LB) X10**4
CATAPULT SEP RATE (FPS)
CARRIER FORCE (LB) X10**4
50.00
25.00
0.00
-25.00
1.50
1.00
0.50
0.00
0
100
200
300
TIME IN MILLISECONDS

ACES II CATAPULT STUDY TEST: 2103 ACCELERATION FIELD: 7 G

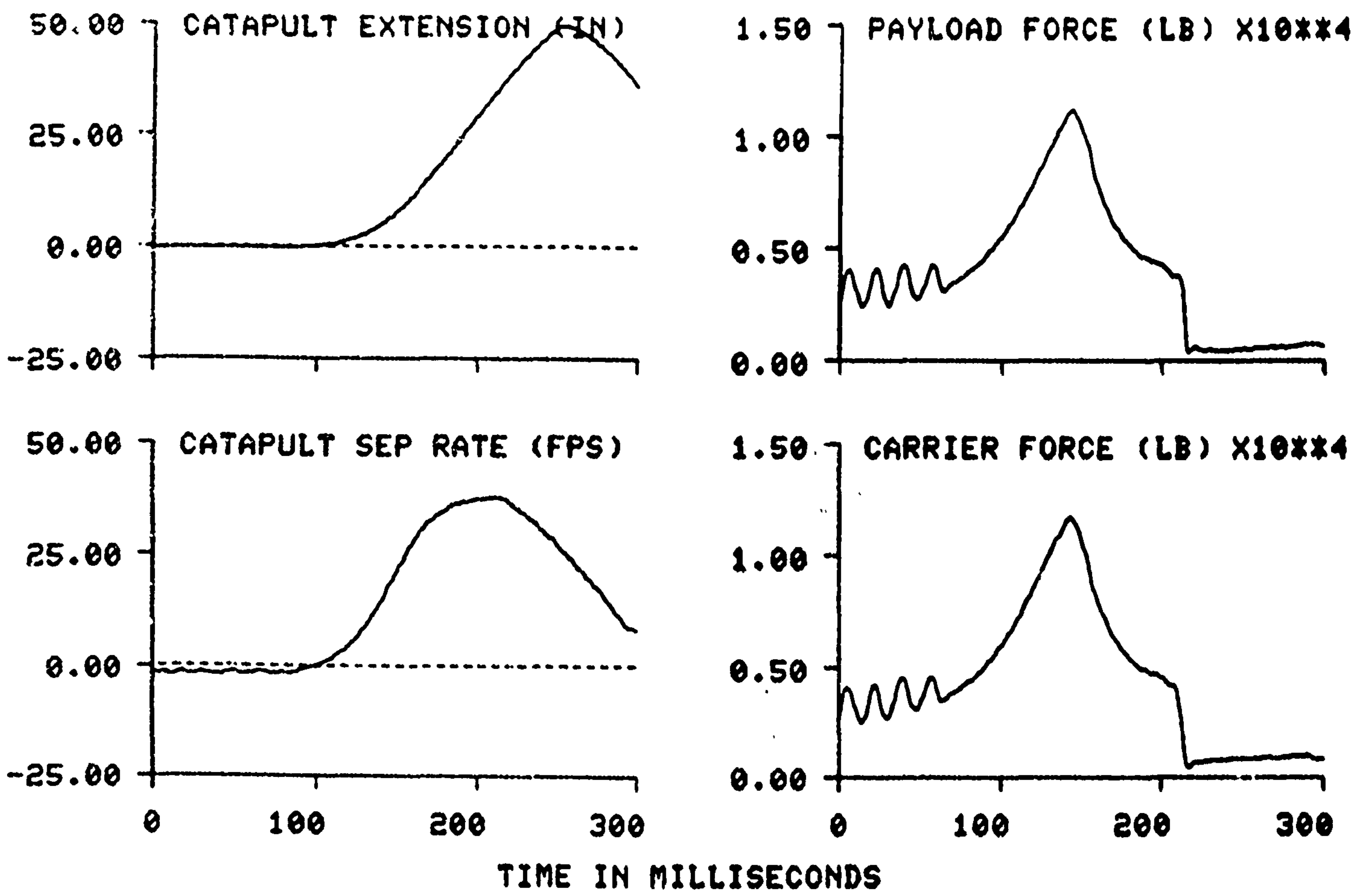


ACES II CATAPULT STUDY TEST: 2104 ACCELERATION FIELD: 7 G 871123
CATAPULT. CKU-5/A SERIAL # 4 TOLERANCE: MAX

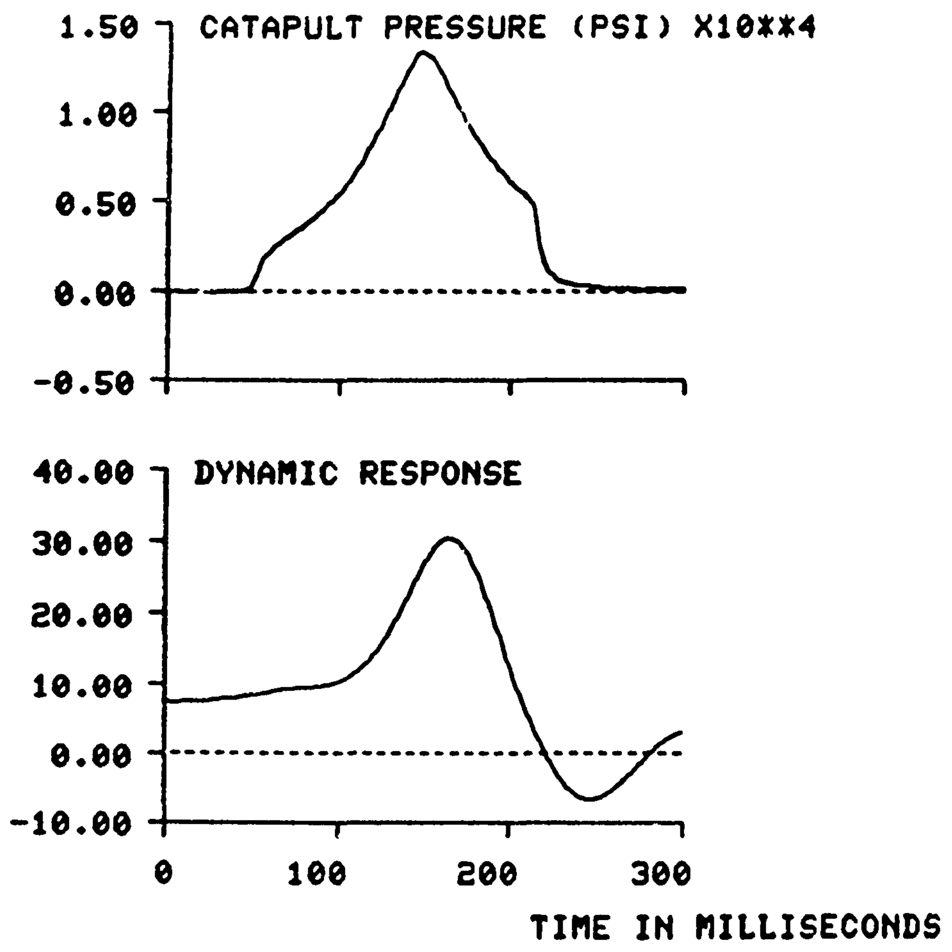
PARAMETER	MAXIMUM VALUE	MINIMUM VALUE	TIME OF MAXIMUM (MS)	TIME OF MINIMUM (MS)
REFERENCE MARK TIME (MS)				
STRIPOFF TIME (MS)			-176.	
PAYLOAD SLED ACCEL (G)			213.	
CARRIER ACCEL @ PAYLOAD MAX (G)	28.15	-5.14	143.	300.
PAYLOAD FORCE (LB)	5 76	-2.25	143.	295.
CARRIER FORCE (LB)	11144 49	399.78	143.	216.
CATAPULT EXTENSION (INCHES)	11741.32	445.35	143.	217.
CATAPULT SEPARATION RATE (FPS)	49.59	-0.14	252.	0.
CATAPULT PRESSURE (PSI)	37.77	-1.96	213.	12.
PAYLOAD VELOCITY (FPS)	13391.70	-49.00	147.	0.
CARRIER VELOCITY (FPS)	9.98	-82.23	234.	0.
STRIPOFF VELOCITY (FPS)	-0.05	-81.02	299.	0.
DYNAMIC RESPONSE INDEX	37.77		213.	
DELAY TIME TO FIRST MOTION (MS)	30.34	-6.81	165.	247.
			97.	


ACES II CATAPULT STUDY TEST: 2104 ACCELERATION FIELD: 7 G
PAYLOAD SLED (G)
30.00
20.00
10.00
0.00
-10.00
PAYLOAD VELOCITY (FPS)
20.00
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
CARRIER SLED (G)
20.00
10.00
0.00
-10.00
-20.00
CARRIER VELOCITY (FPS)
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
0
100
200
300
TIME IN MILLISECONDS

ACES II CATAPULT STUDY TEST: 2104 ACCELERATION FIELD: 7 G

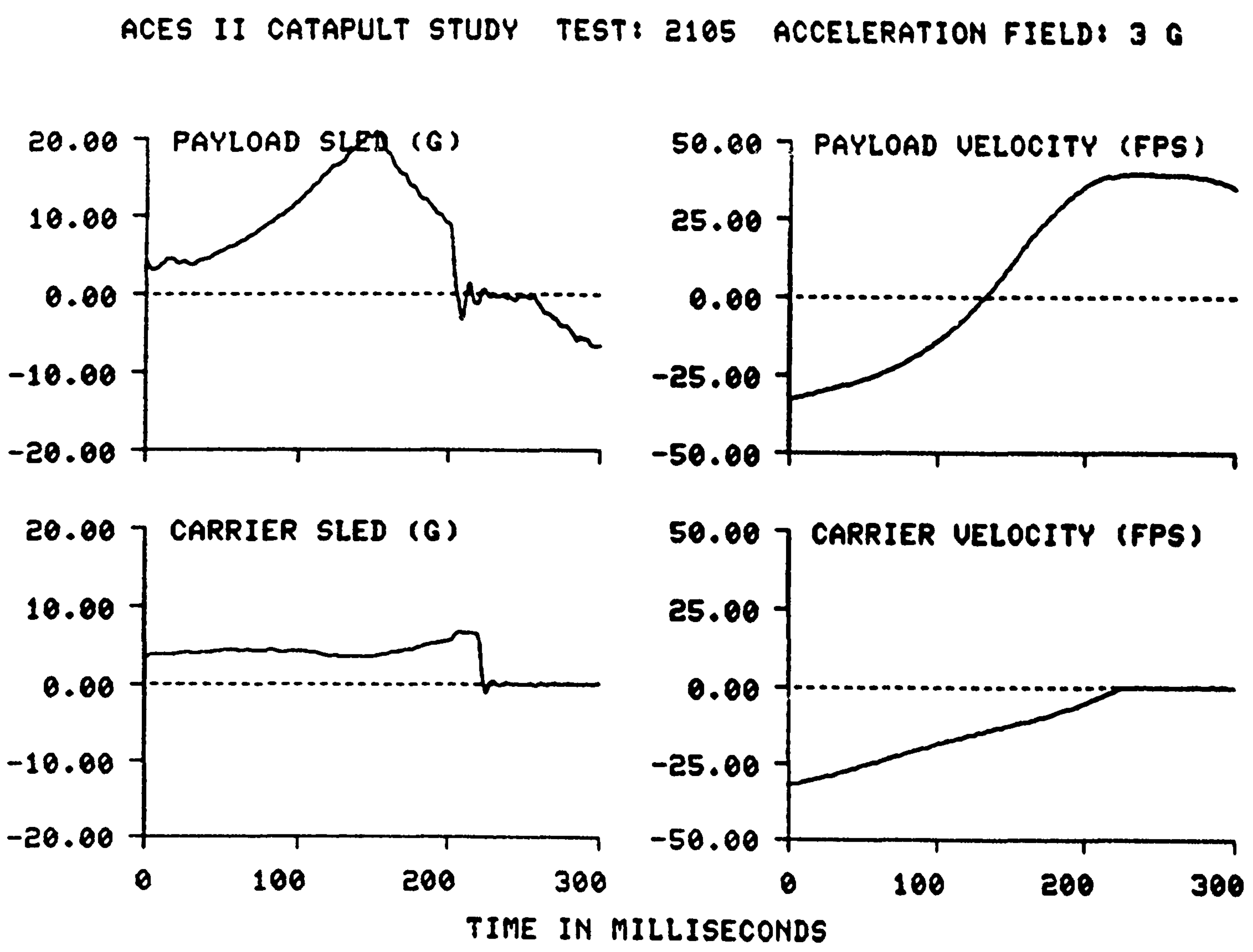


ACES II CATAPULT STUDY TEST: 2104 ACCELERATION FIELD: 7 G

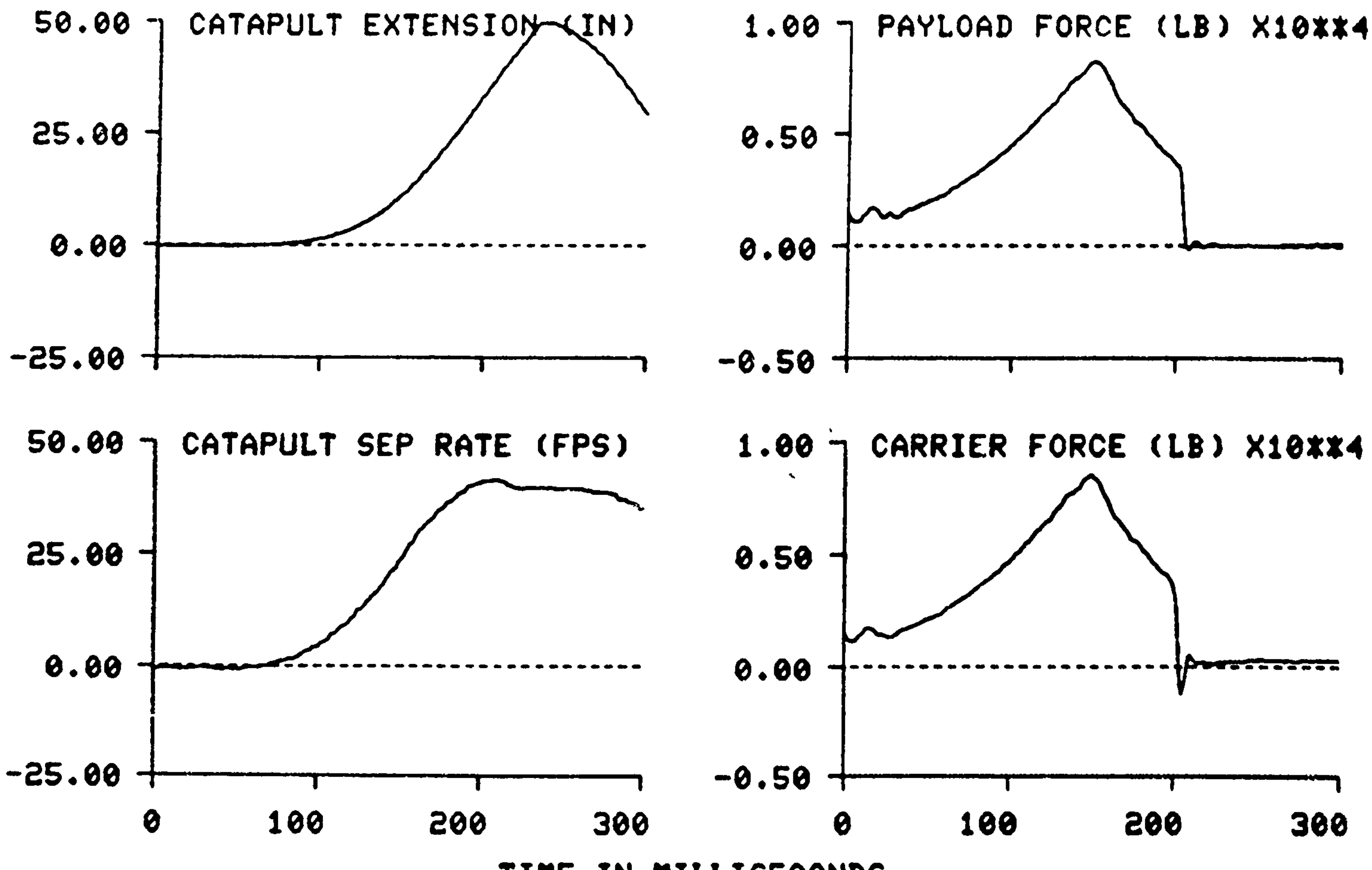


ACES II CATAPULT STUDY TEST: 2105 ACCELERATION FIELD: 3 G 871124
CATAPULT: CKU-5/A SERIAL #: 7 TOLERANCE: MIN

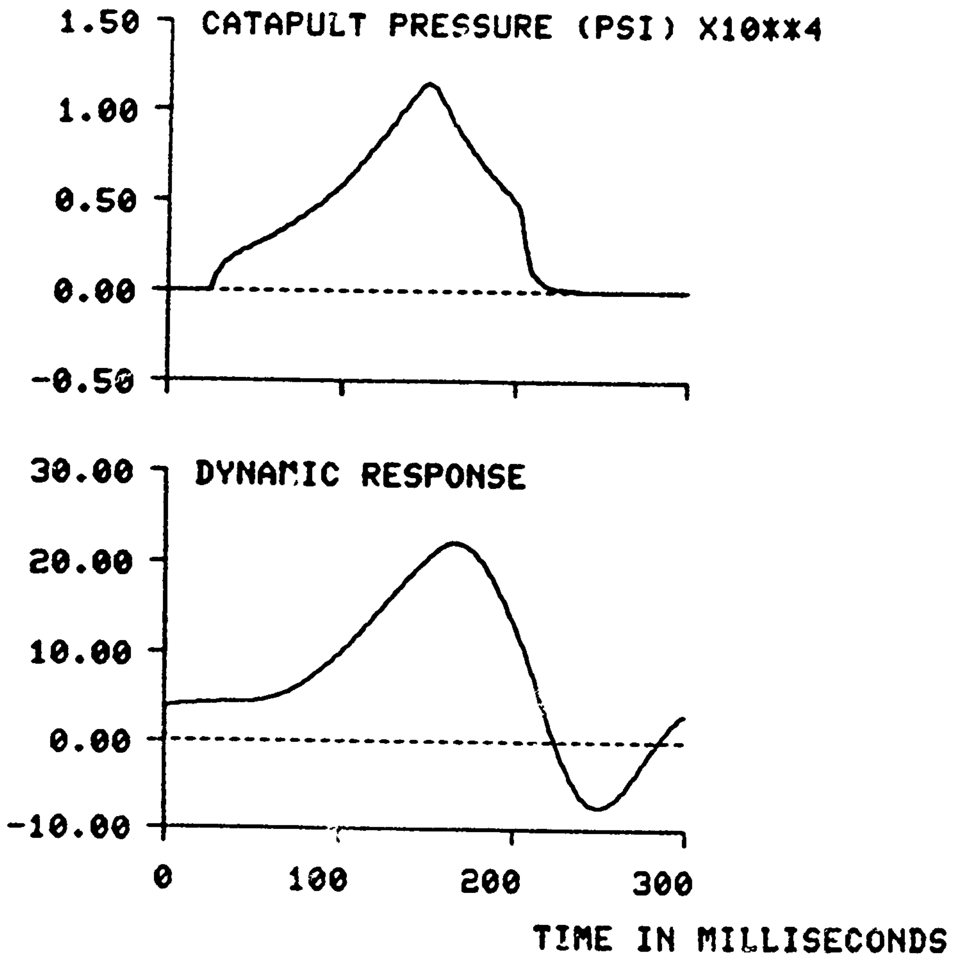
PARAMETER	MAXIMUM VALUE	MINIMUM VALUE	TIME OF MAXIMUM (MS)	TIME OF MINIMUM (MS)
REFERENCE MARK TIME (MS)			-162.	
STRIPOFF TIME (MS)			203.	
PAYLOAD SLED ACCEL (G)	20.97	-6.63	151.	296.
CARRIER ACCEL @ PAYLOAD MAX (G)	3.50	-1.19	151.	225.
PAYLOAD FORCE (LB)	8244.94	-150.93	149.	207.
CARRIER FORCE (LB)	8551.95	-1219.56	149.	205.
CATAPULT EXTENSION (INCHES)	49.95	-0.03	235.	0.
CATAPULT SEPARATION RATE (FPS)	41.58	-0.90	208.	0.
CATAPULT PRESSURE (PSI)	11487.02	-5.03	148.	0.
PAYLOAD VELOCITY (FPS)	39.75	-32.97	225.	0.
CARRIER VELOCITY (FPS)	0.17	-32.07	235.	0.
STRIPOFF VELOCITY (FPS)	41.33		203.	
DYNAMIC RESPONSE INDEX	22.14	-7.56	167.	251.
DELAY TIME TO FIRST MOTION (MS)			72.	


ACES II CATAPULT STUDY TEST: 2105 ACCELERATION FIELD: 3 G
PAYLOAD SLED (G)
PAYLOAD VELOCITY (FPS)
CARRIER SLED (G)
CARRIER VELOCITY (FPS)
20.00
10.00
0.00
-10.00
-20.00
50.00
25.00
0.00
-25.00
-50.00
0
100
200
300
TIME IN MILLISECONDS

ACES II CATAPULT STUDY TEST: 2105 ACCELERATION FIELD: 3 G



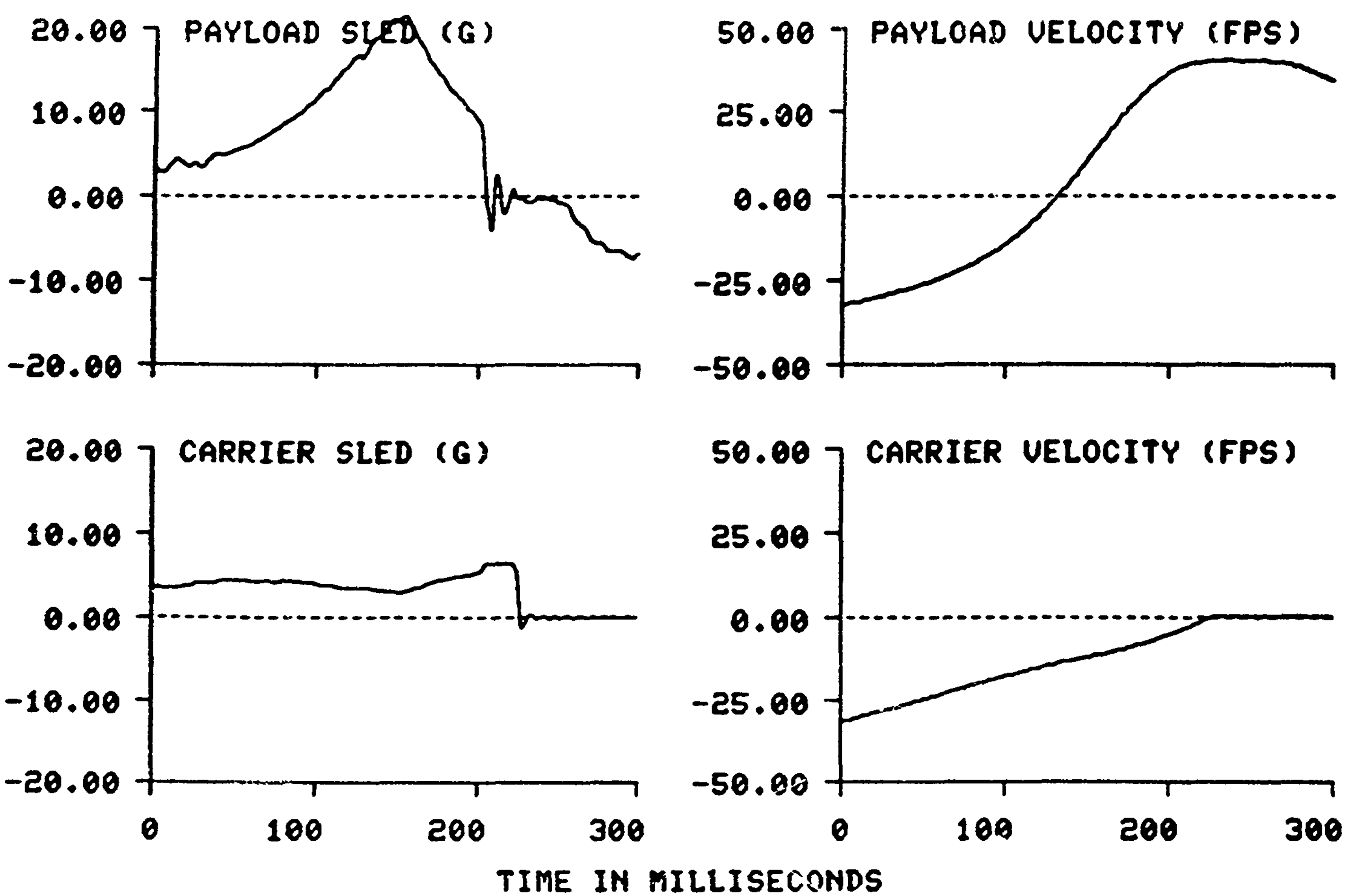
ACES II CATAPULT STUDY TEST: 2105 ACCELERATION FIELD: 3 G

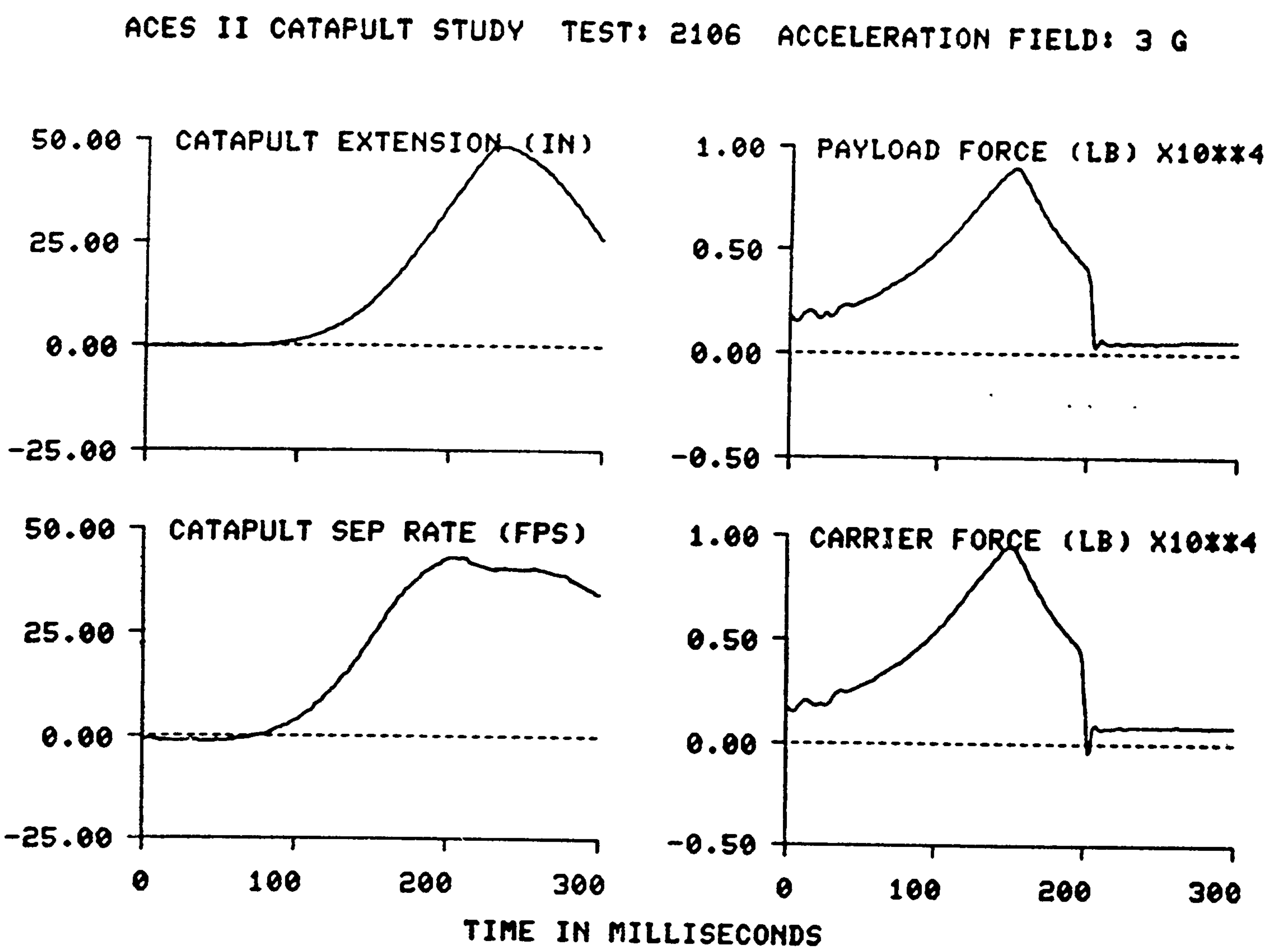


ACES II CATAPULT STUDY TEST: 2106 ACCELERATION FIELD: 3 G 871124
CATAPULT: CKU-5/A SERIAL #: 5 TOLERANCE: MAX

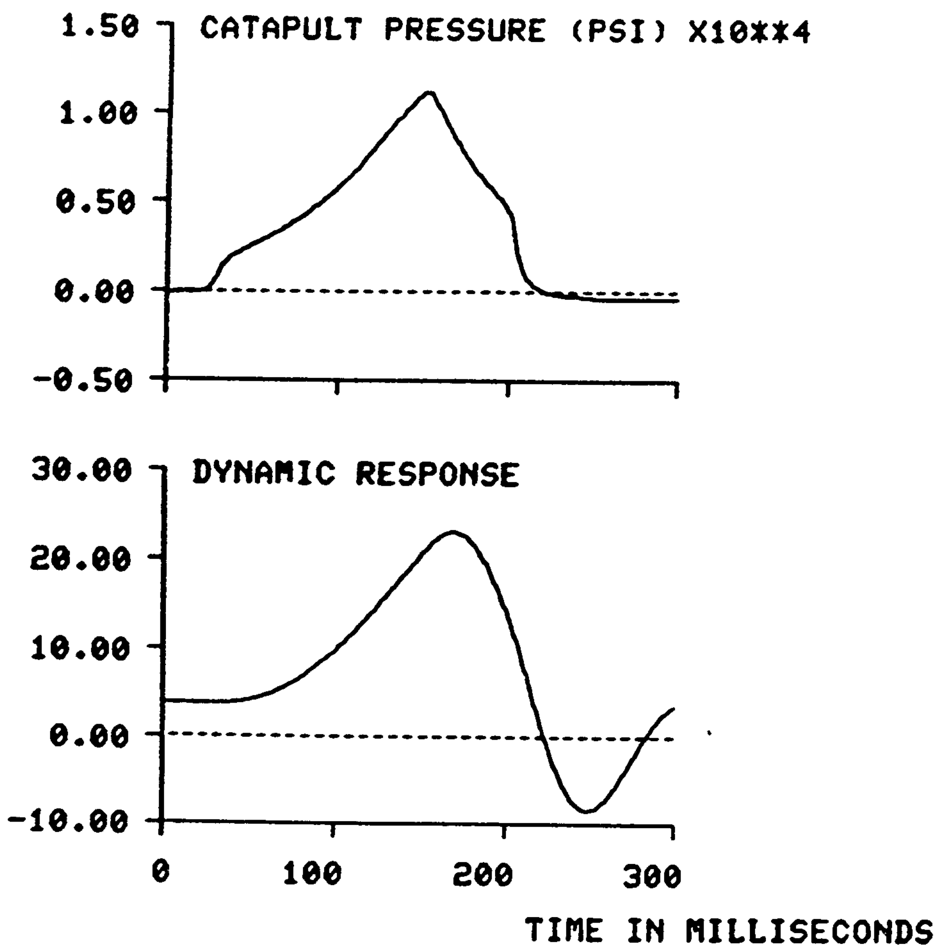
PARAMETER	MAXIMUM VALUE	MINIMUM VALUE	TIME OF MAXIMUM (MS)	TIME OF MINIMUM (MS)
REFERENCE MARK TIME (MS)			-170.	
STRIPOFF TIME (MS)			201.	
PAYLOAD SLED ACCEL (G)	21.58	-7.31	153.	296.
CARRIER ACCEL @ PAYLOAD MAX (G)	2.94	-1.19	153.	228.
PAYLOAD FORCE (LB)	9001.06	305.34	150.	205.
CARRIER FORCE (LB)	9524.10	-422.35	150.	203.
CATAPULT EXTENSION (INCHES)	48.49	-0.24	229.	6.
CATAPULT SEPARATION RATE (FPS)	43.16	-1.32	205.	38.
CATAPULT PRESSURE (PSI)	11197.23	-394.75	150.	264.
PAYLOAD VELOCITY (FPS)	40.80	-32.67	232.	0.
CARRIER VELOCITY (FPS)	0.39	-31.85	231.	0.
STRIPOFF VELOCITY (FPS)	42.66		201.	
DYNAMIC RESPONSE INDEX	23.03	-8.49	169.	249.
DELAY TIME TO FIRST MOTION (MS)			74.	

ACES II CATAPULT STUDY TEST: 2106 ACCELERATION FIELD: 3 G




ACES II CATAPULT STUDY TEST: 2106 ACCELERATION FIELD: 3 G
CATAPULT EXTENSION (IN)
50.00
25.00
0.00
-25.00
PAYLOAD FORCE (LB) X10**4
1.00
0.50
0.00
-0.50
CATAPULT SEP RATE (FPS)
50.00
25.00
0.00
-25.00
CARRIER FORCE (LB) X10**4
1.00
0.50
0.00
-0.50
0
100
200
300
0
100
200
300
TIME IN MILLISECONDS

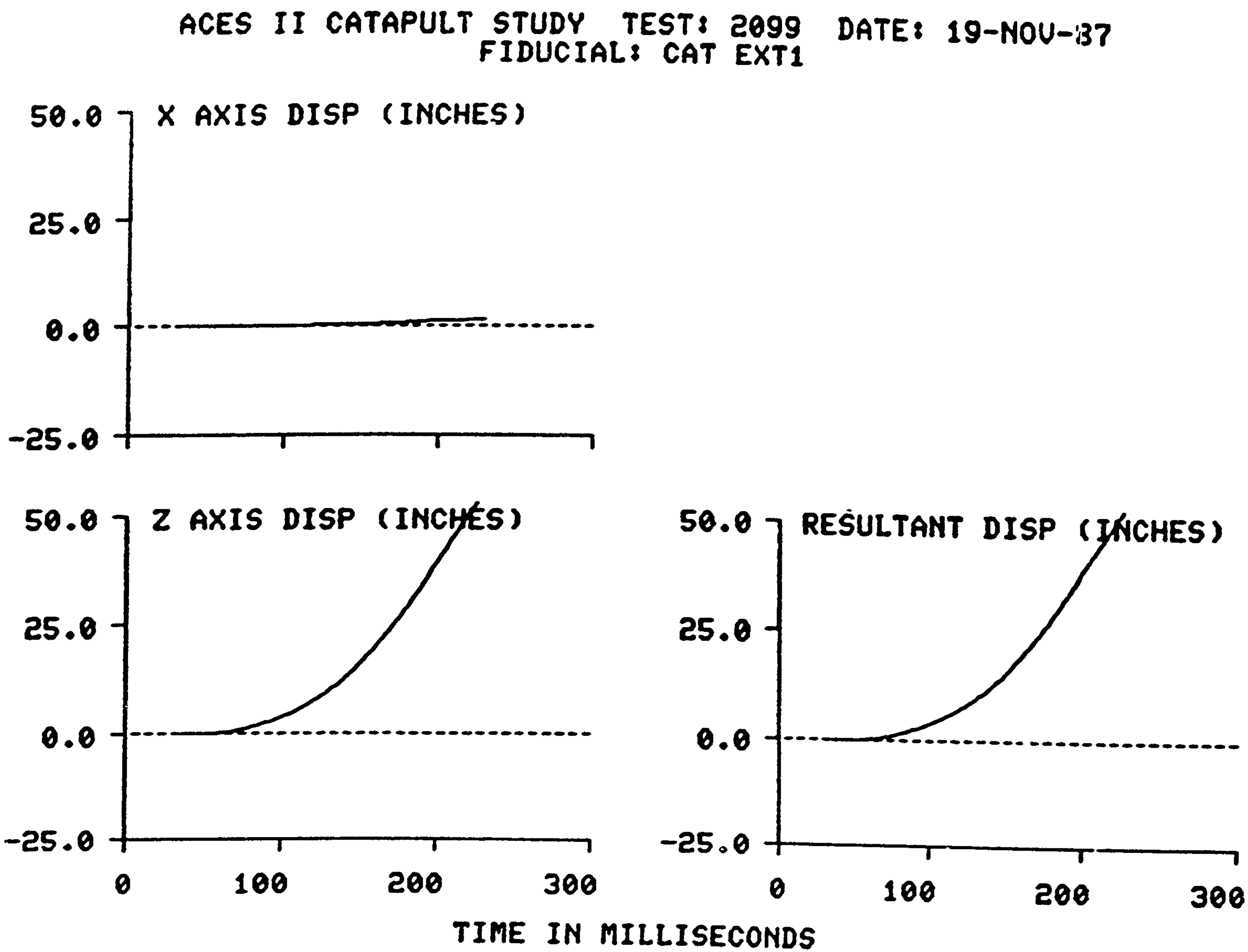
ACES II CATAPULT STUDY TEST: 2106 ACCELERATION FIELD: 3 G

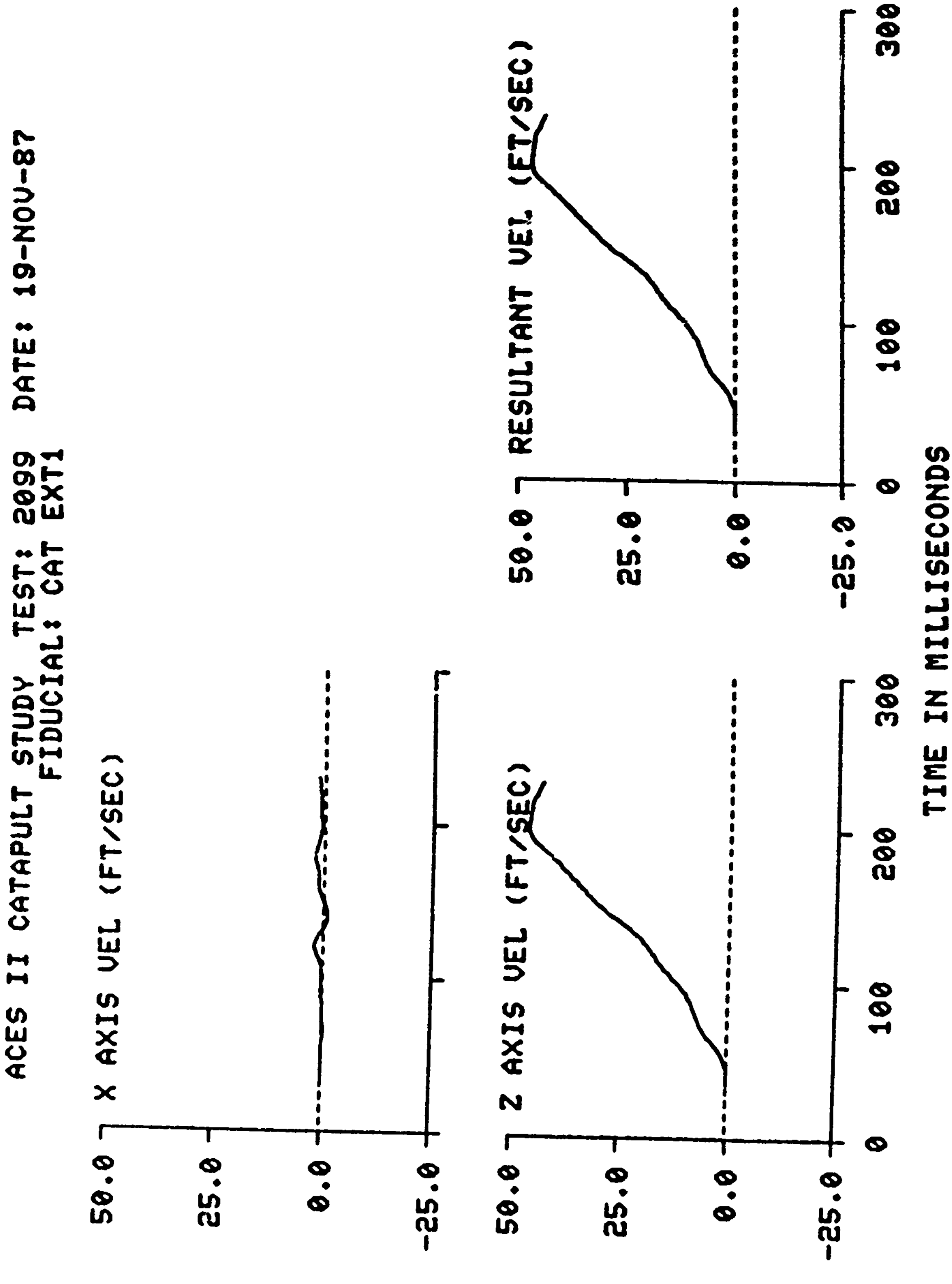


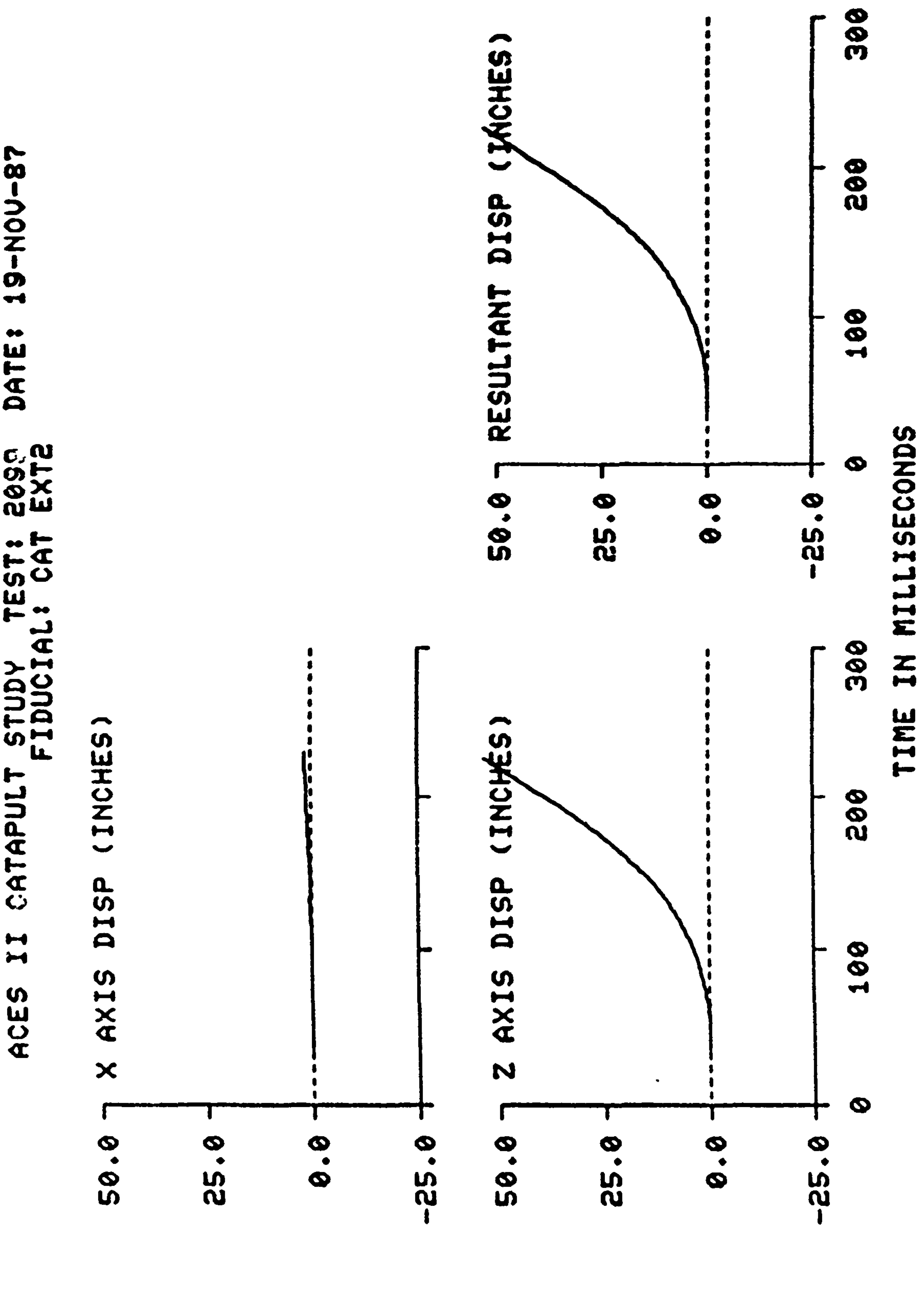
APPENDIX C

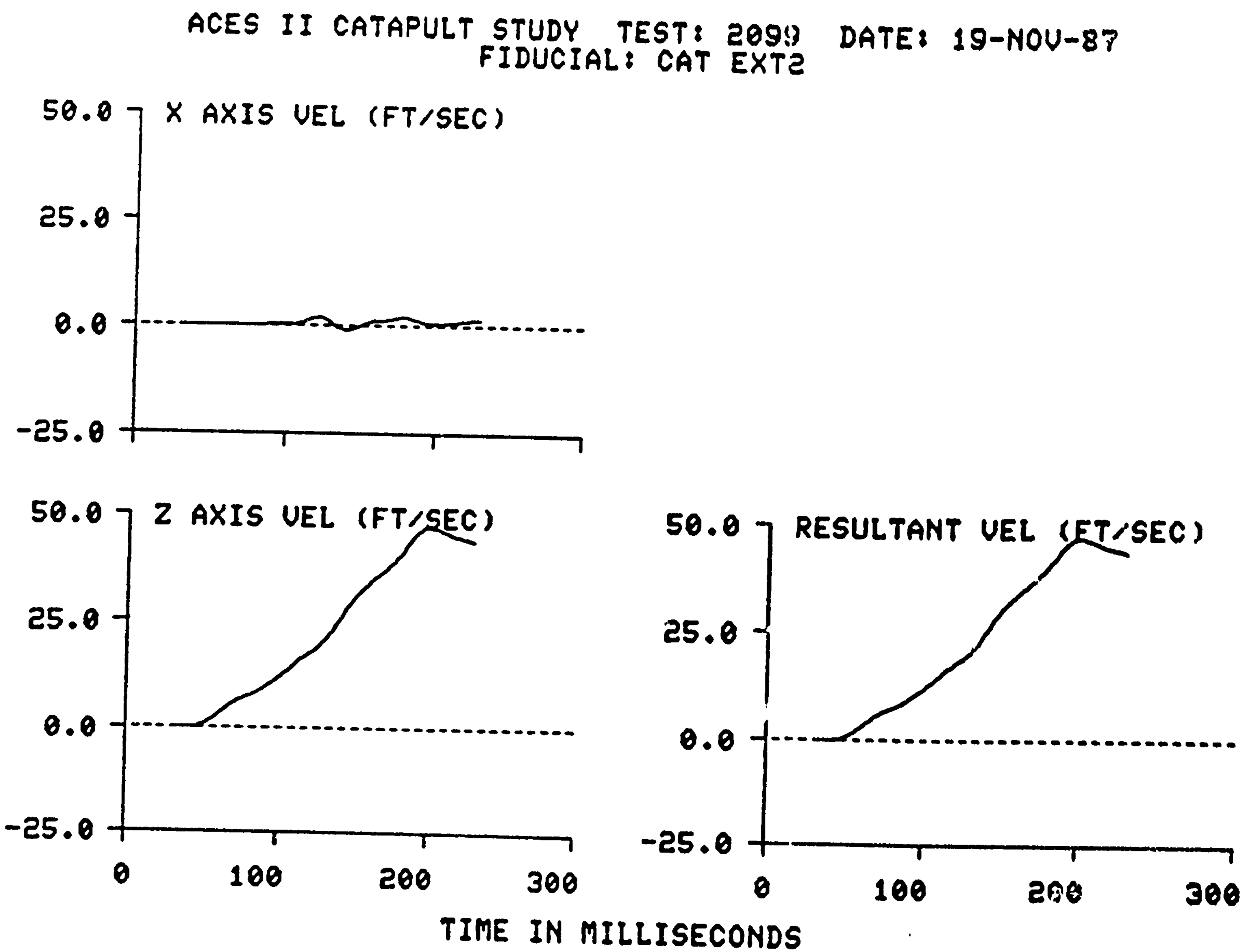
SUMMARIES AND PLOTS OF PHOTOGRAMMETRIC TEST DATA

The following plots present the catapult extension and extension rate for each test as measured from the high-speed photographic film.

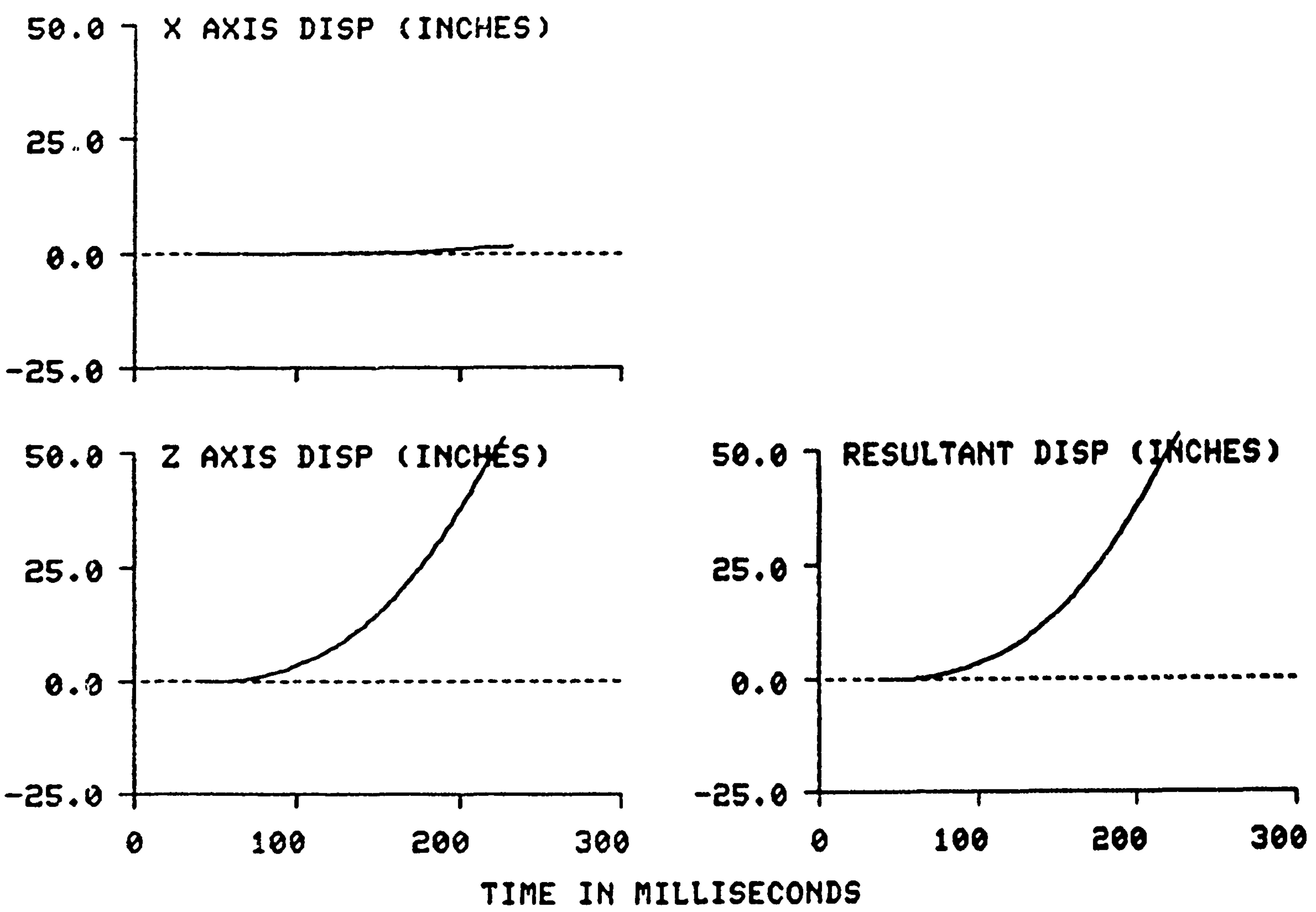

ACES II CATAPULT STUDY TEST: 2099 DATE: 19-NOV-87
FIDUCIAL: CAT EXT1
X AXIS DISP (INCHES)
Z AXIS DISP (INCHES)
RESULTANT DISP (INCHES)
50.0
25.0
0.0
-25.0
0
100
200
300
TIME IN MILLISECONDS


ACES II CATAPULT STUDY TEST: 2099 DATE: 19-NOV-87
FIDUCIAL: CAT EXT1
X AXIS VEL (FT/SEC)
Z AXIS VEL (FT/SEC)
RESULTANT VEL (FT/SEC)
50.0
25.0
0.0
-25.0
0
100
200
300
TIME IN MILLISECONDS

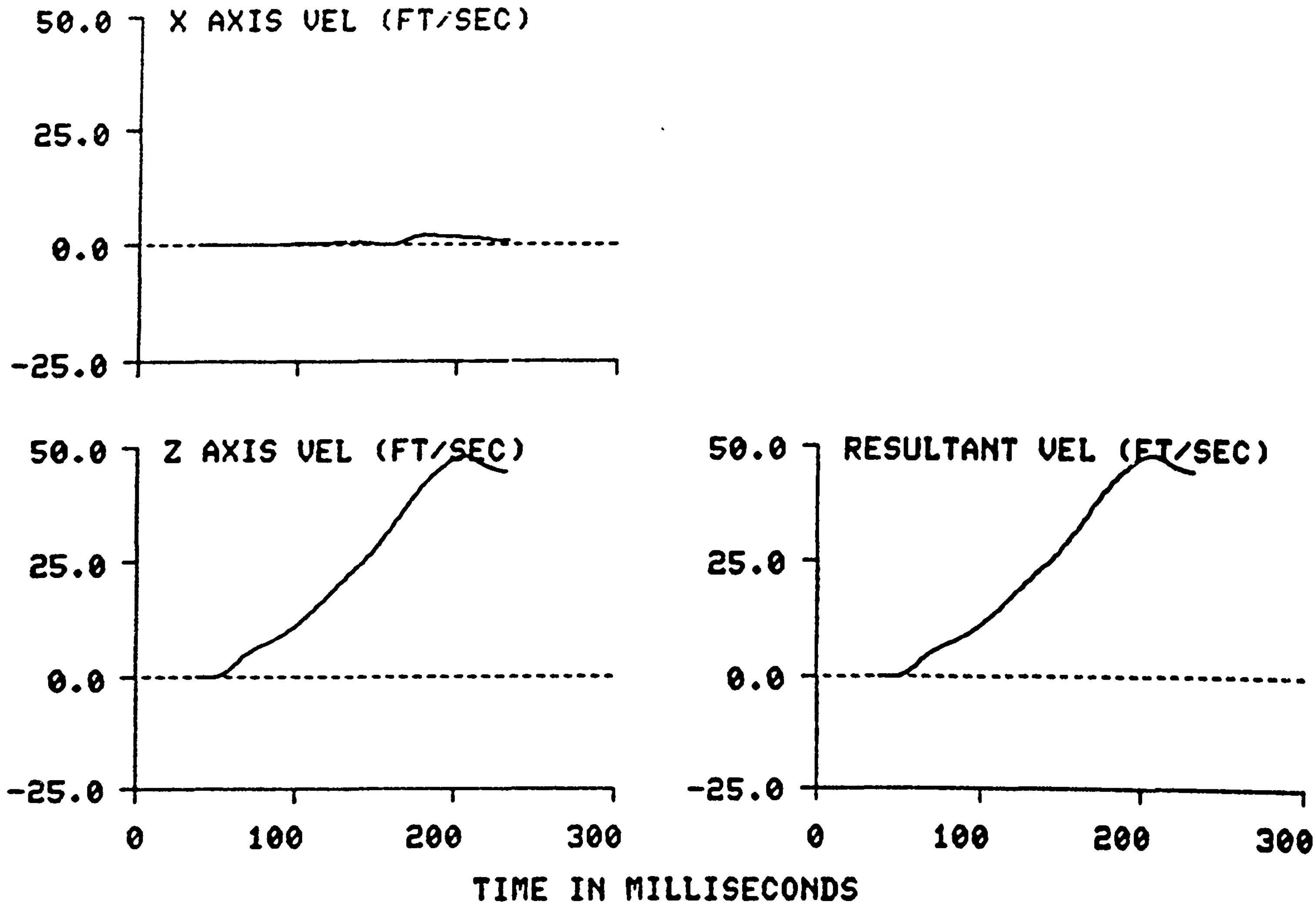

ACES II CATAPULT STUDY TEST: 2099 DATE: 19-NOV-87
FIDUCIAL: CAT EXT2
X AXIS DISP (INCHES)
Z AXIS DISP (INCHES)
RESULTANT DISP (INCHES)
50.0
25.0
0.0
-25.0
0
100
200
300
TIME IN MILLISECONDS

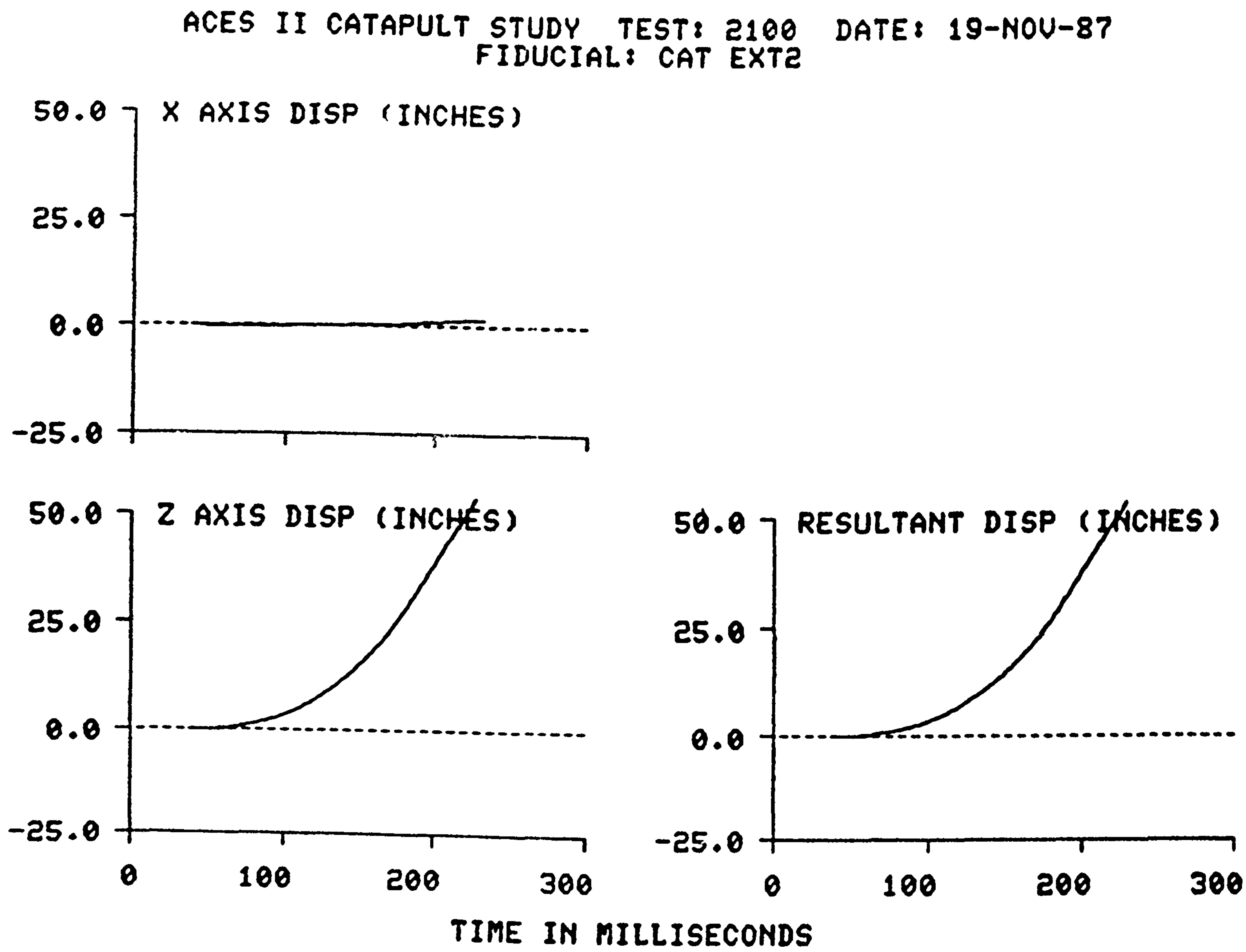

ACES II CATAPULT STUDY TEST: 2099 DATE: 19-NOV-87
FIDUCIAL: CAT EXT2
X AXIS VEL (FT/SEC)
50.0
25.0
0.0
-25.0
Z AXIS VEL (FT/SEC)
50.0
25.0
0.0
-25.0
0
100
200
300
RESULTANT VEL (FT/SEC)
50.0
25.0
0.0
-25.0
0
100
200
300
TIME IN MILLISECONDS

ACES II CATAPULT STUDY TEST: 2100 DATE: 19-NOV-87
FIDUCIAL: CAT EXT1

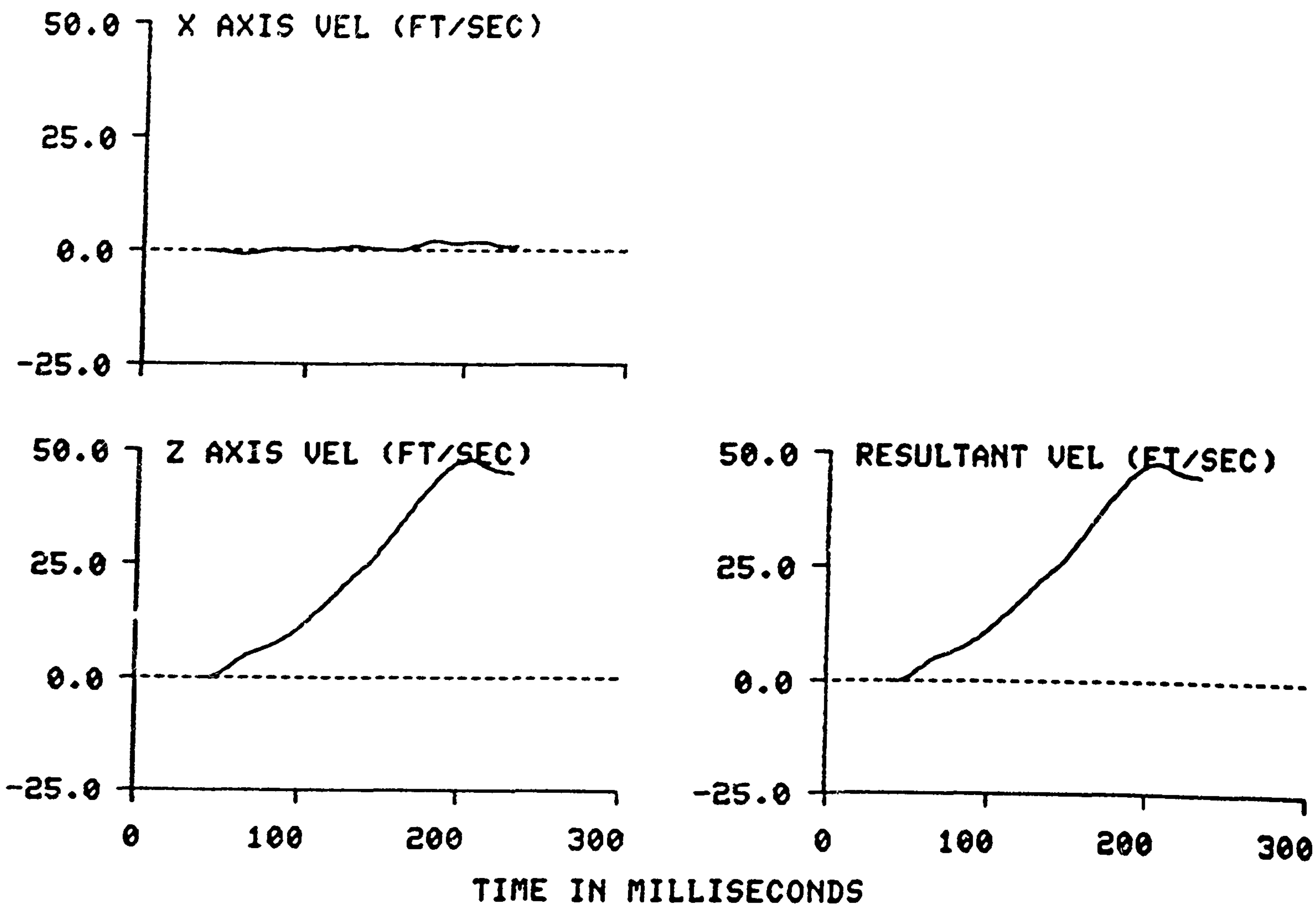


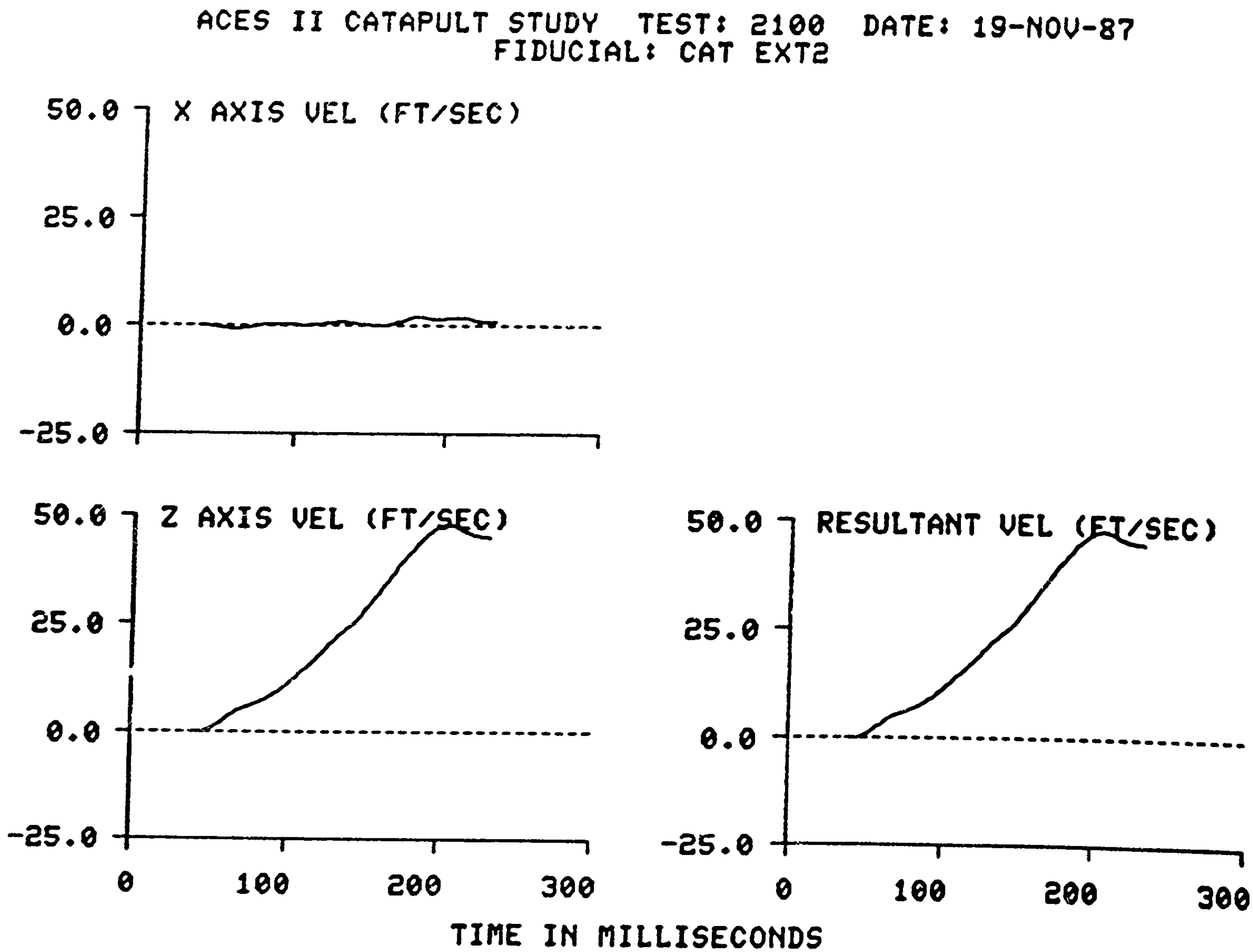
ACES II CATAPULT STUDY TEST: 2100 DATE: 19-NOV-87
FIDUCIAL: CAT EXT1



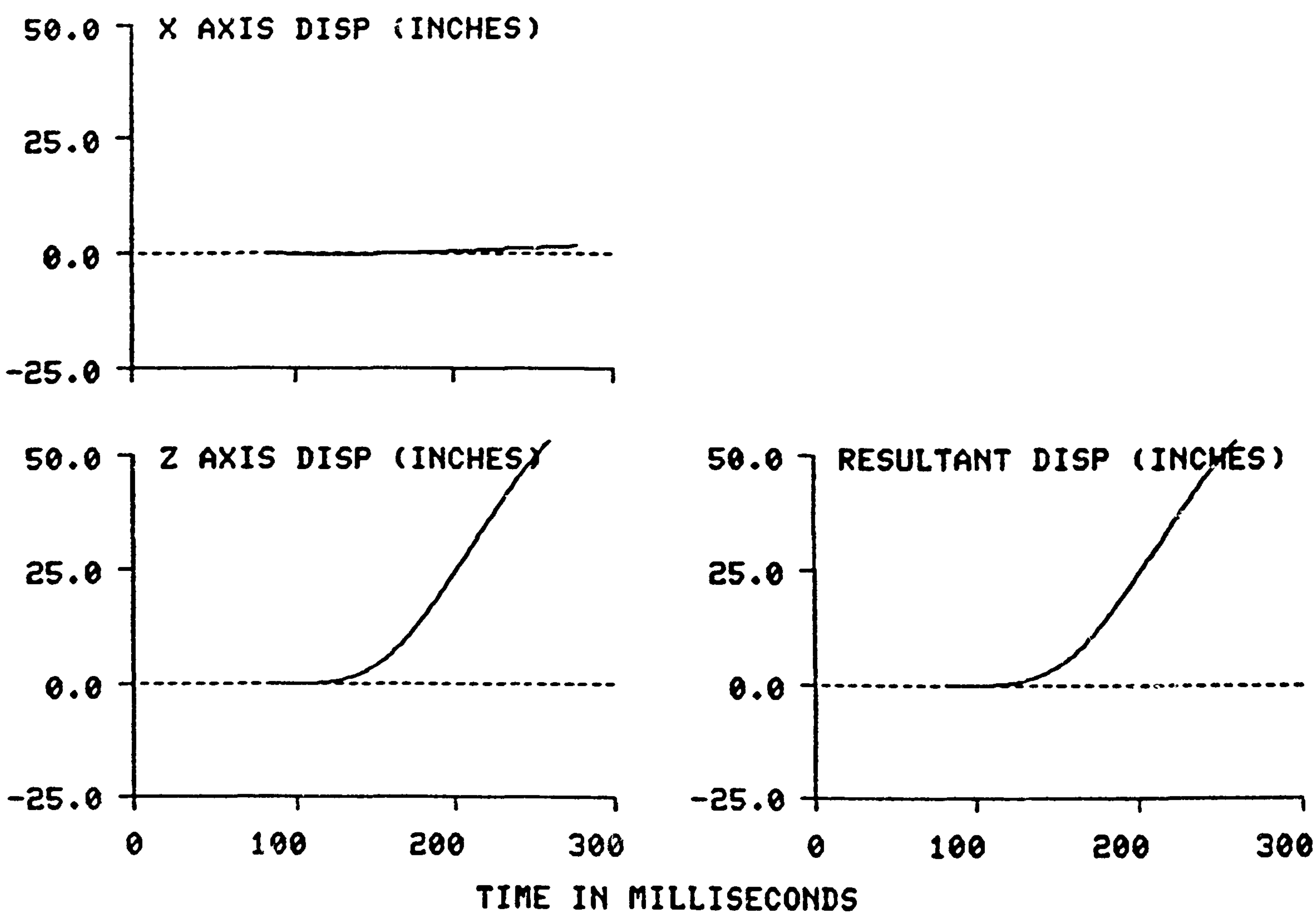

ACES II CATAPULT STUDY TEST: 2100 DATE: 19-NOV-87
FIDUCIAL: CAT EXT2
X AXIS DISP (INCHES)
Z AXIS DISP (INCHES)
RESULTANT DISP (INCHES)
50.0
25.0
0.0
-25.0
0
100
200
300
TIME IN MILLISECONDS

ACES II CATAPULT STUDY TEST: 2100 DATE: 19-NOV-87
FIDUCIAL: CAT EXT2

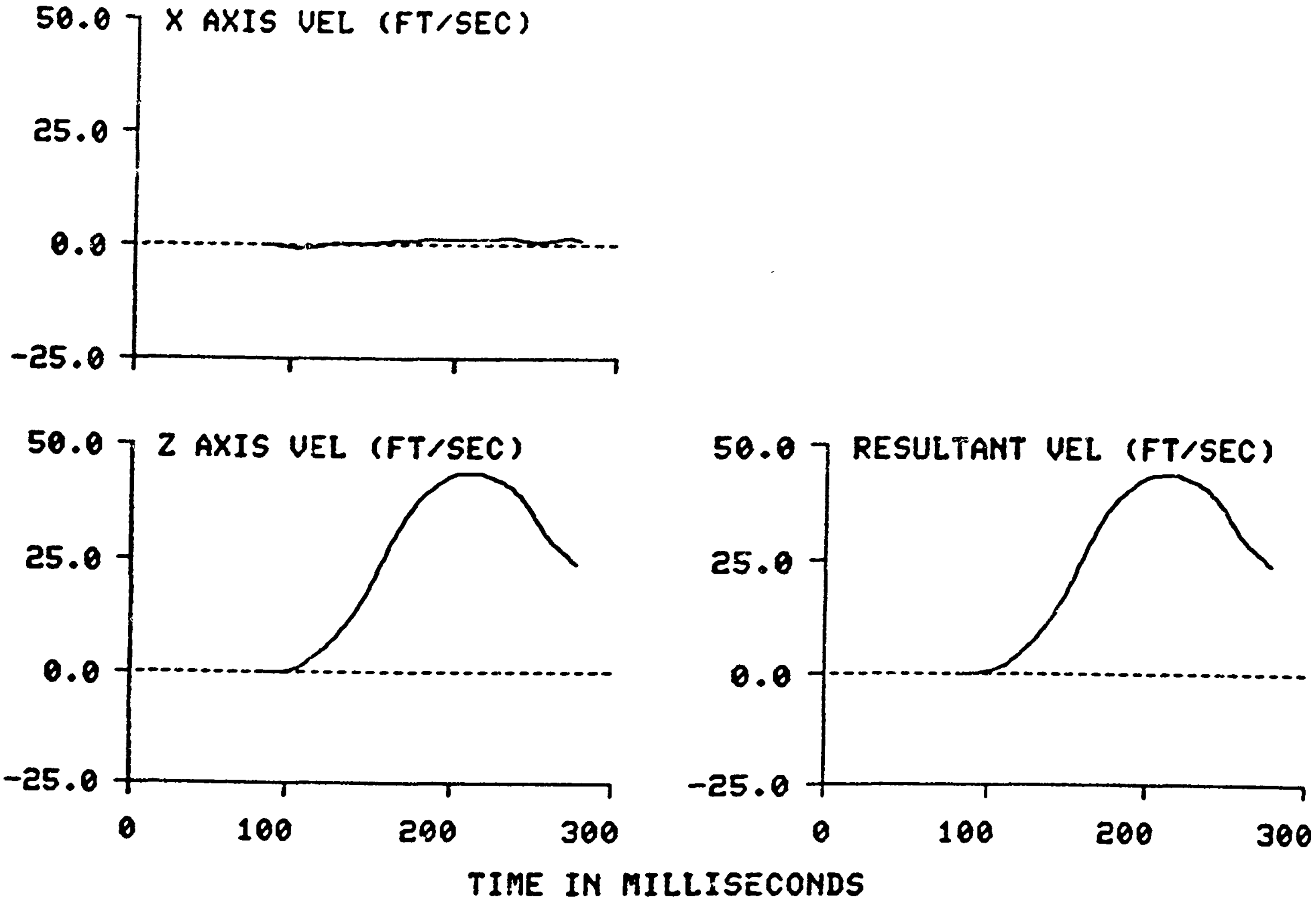


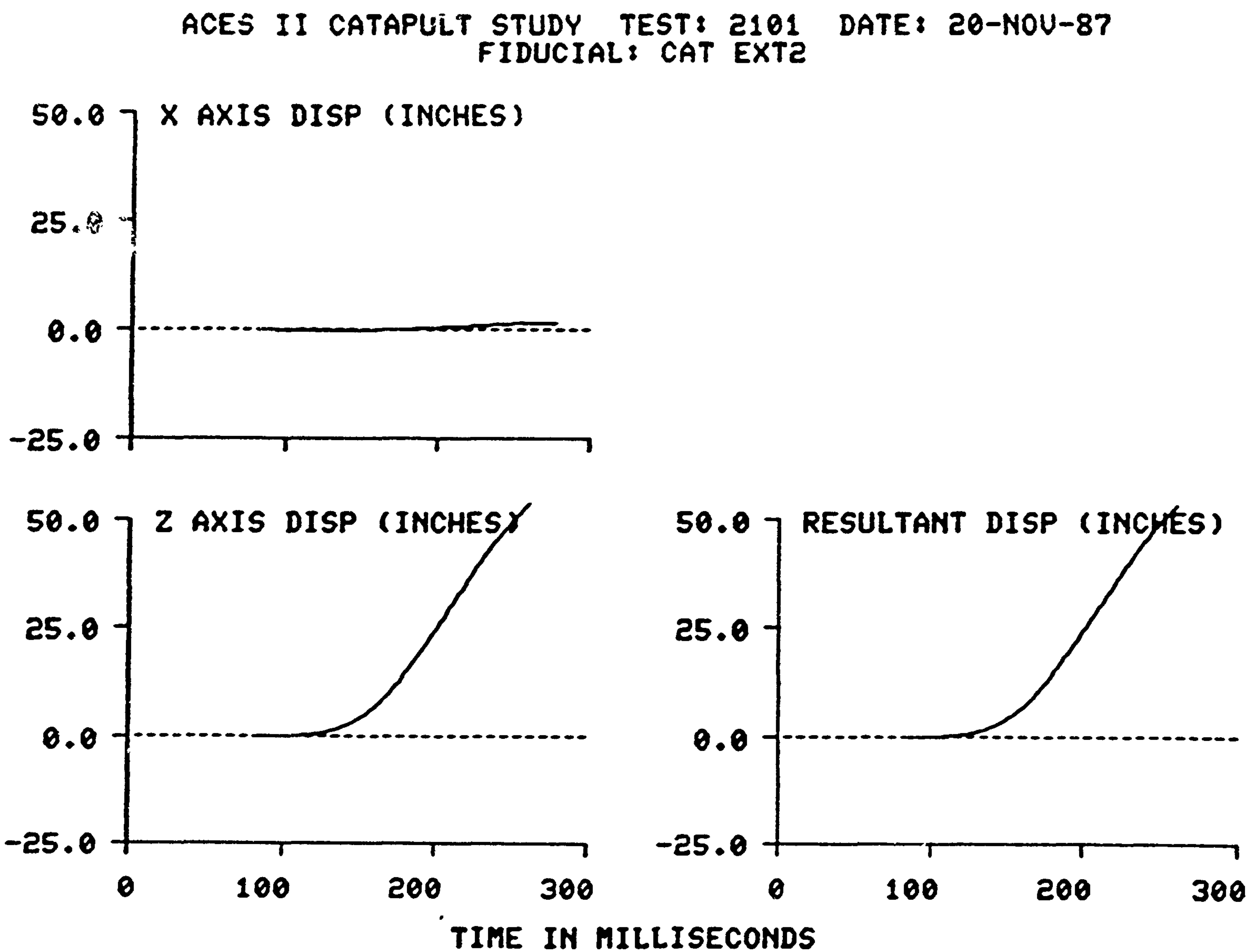

ACES II CATAPULT STUDY TEST: 2100 DATE: 19-NOV-87
FIDUCIAL: CAT EXT2
X AXIS VEL (FT/SEC)
Z AXIS VEL (FT/SEC)
RESULTANT VEL (FT/SEC)
50.0
25.0
0.0
-25.0
0
100
200
300
TIME IN MILLISECONDS

ACES II CATAPULT STUDY TEST: 2101 DATE: 20-NOV-87
FIDUCIAL: CAT EXT1

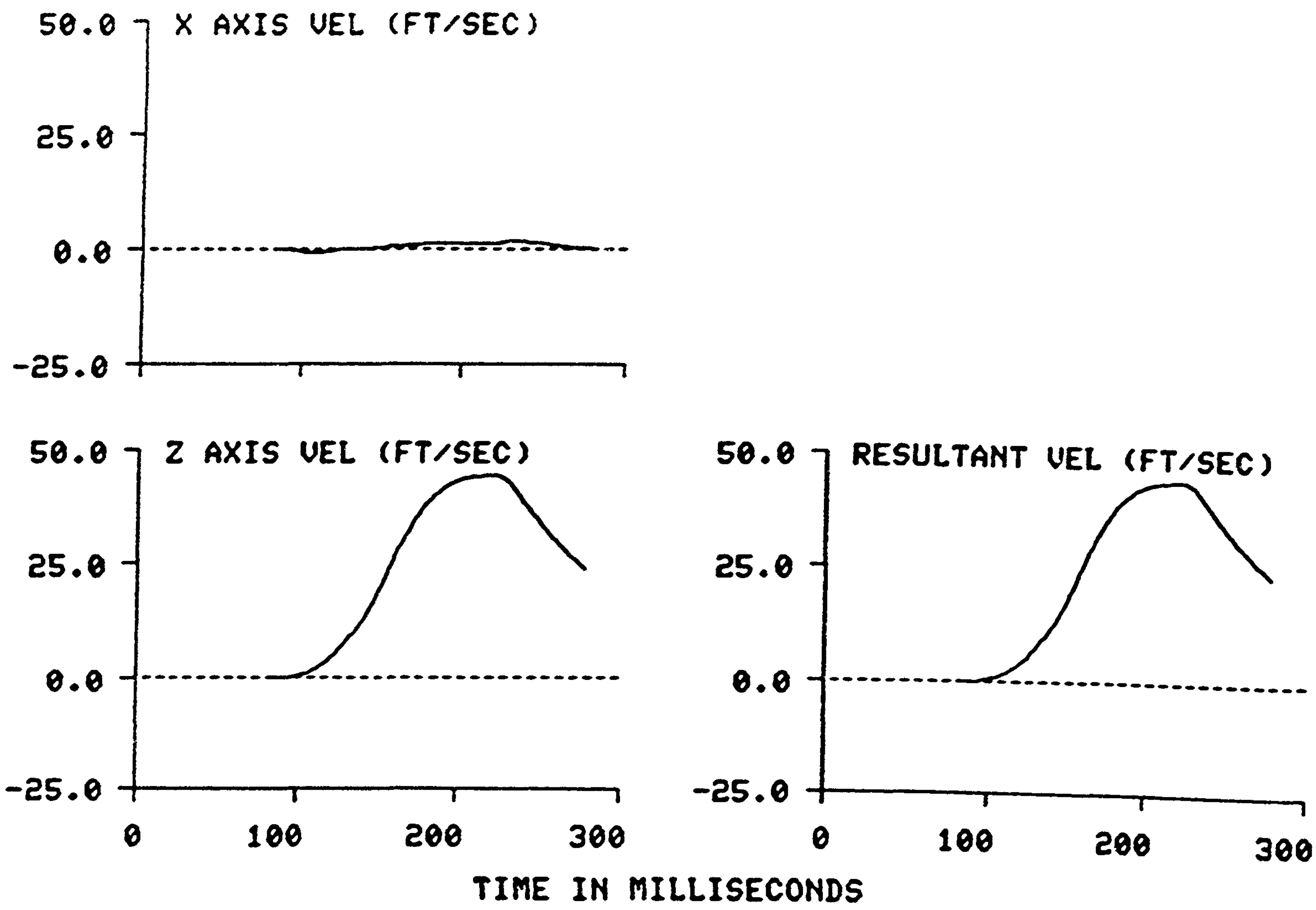


ACES II CATAPULT STUDY TEST: 2101 DATE: 20-NOV-87
FIDUCIAL: CAT EXT1

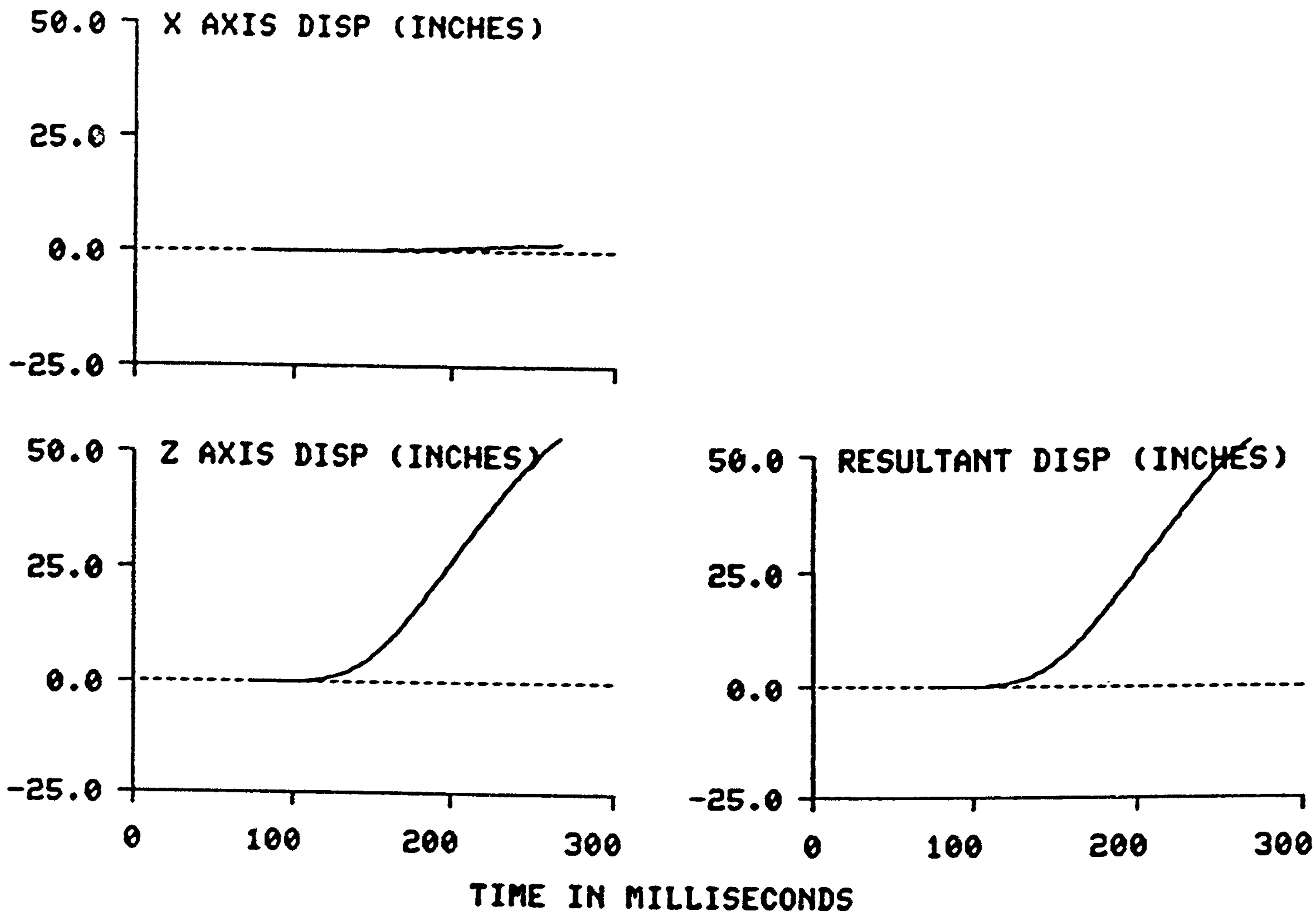


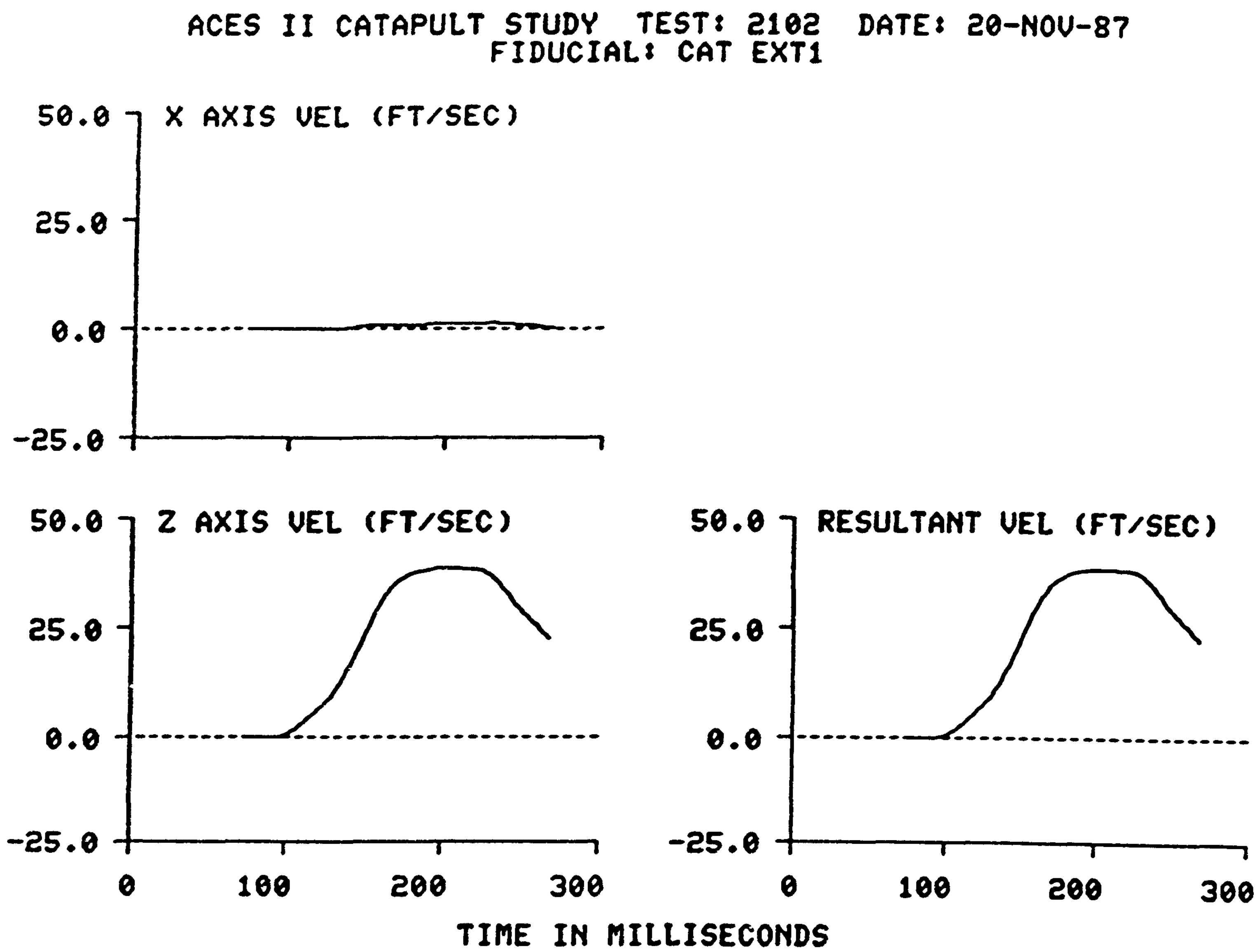

ACES II CATAPULT STUDY TEST: 2101 DATE: 20-NOV-87
FIDUCIAL: CAT EXT2
X AXIS DISP (INCHES)
Z AXIS DISP (INCHES)
RESULTANT DISP (INCHES)
50.0
25.0
0.0
-25.0
0
100
200
300
TIME IN MILLISECONDS

ACES II CATAPULT STUDY TEST: 2101 DATE: 20-NOV-87
FIDUCIAL: CAT EXT2

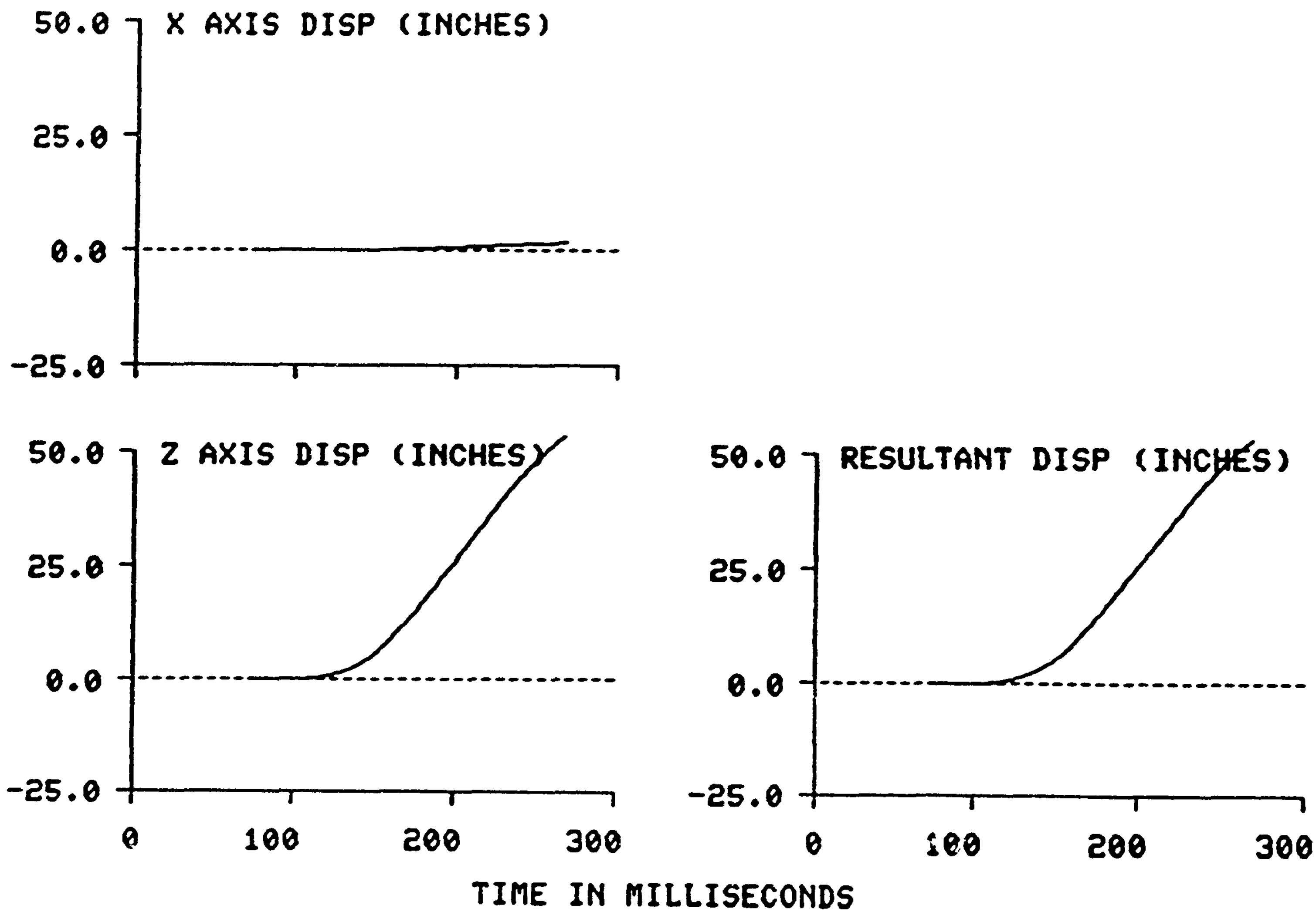


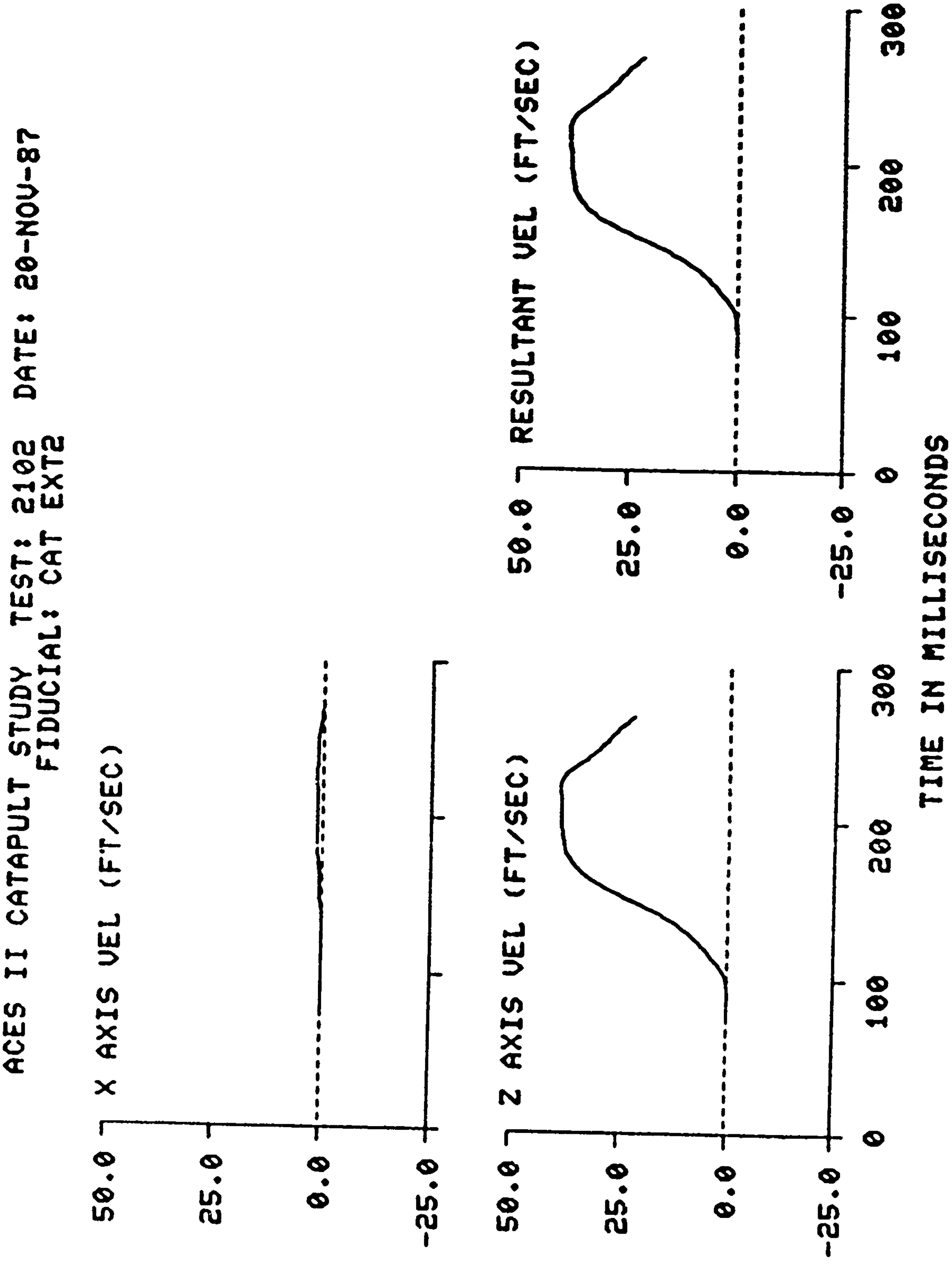
ACES II CATAPULT STUDY TEST: 2102 DATE: 20-NOV-87
FIDUCIAL: CAT EXT1



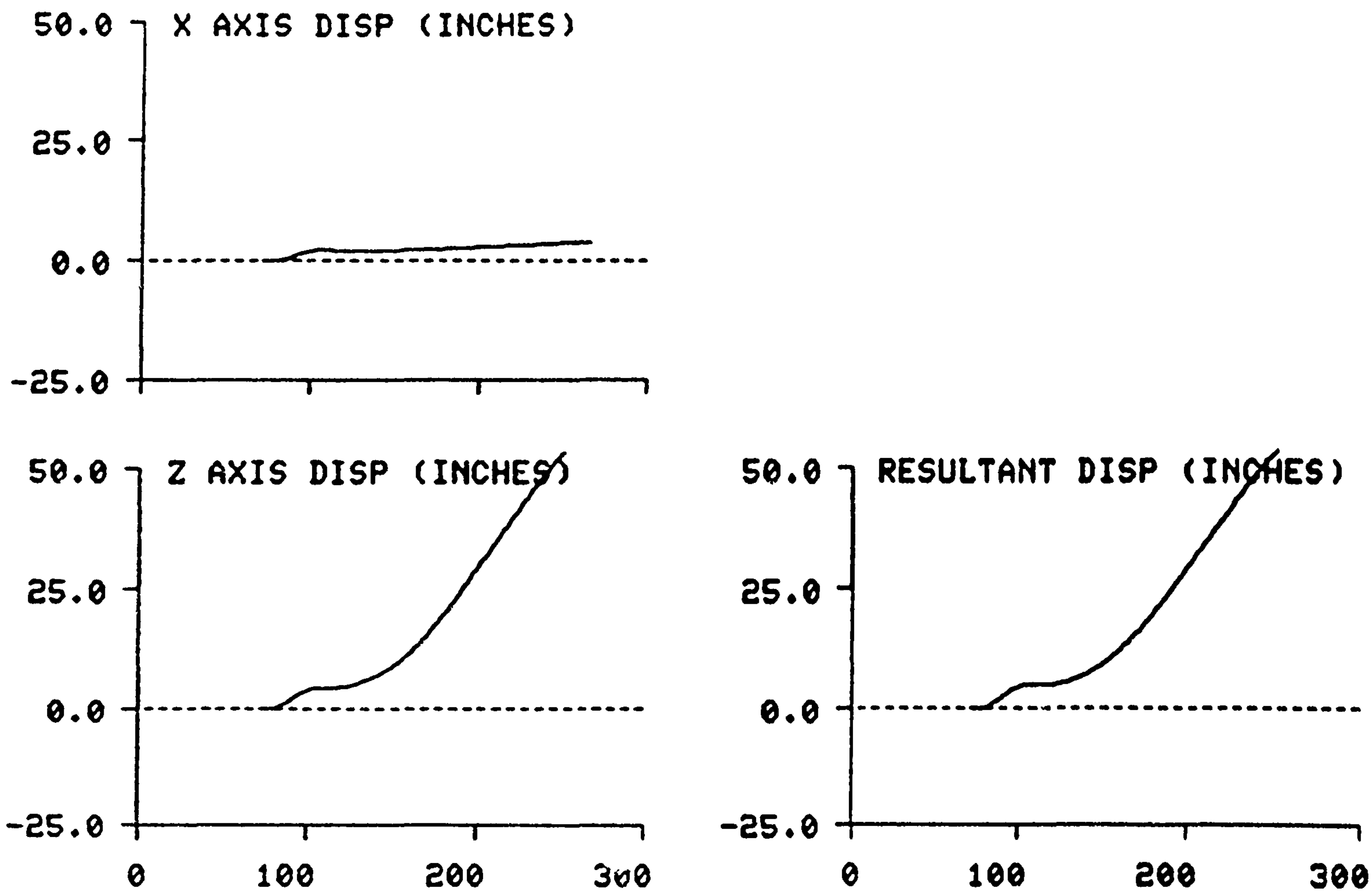

ACES II CATAPULT STUDY TEST: 2102 DATE: 20-NOV-87
FIDUCIAL: CAT EXT1
X AXIS VEL (FT/SEC)
Z AXIS VEL (FT/SEC)
RESULTANT VEL (FT/SEC)
50.0
25.0
0.0
-25.0
0
100
200
300
TIME IN MILLISECONDS

ACES II CATAPULT STUDY TEST: 2102 DATE: 20-NOV-87
FIDUCIAL: CAT EXT2



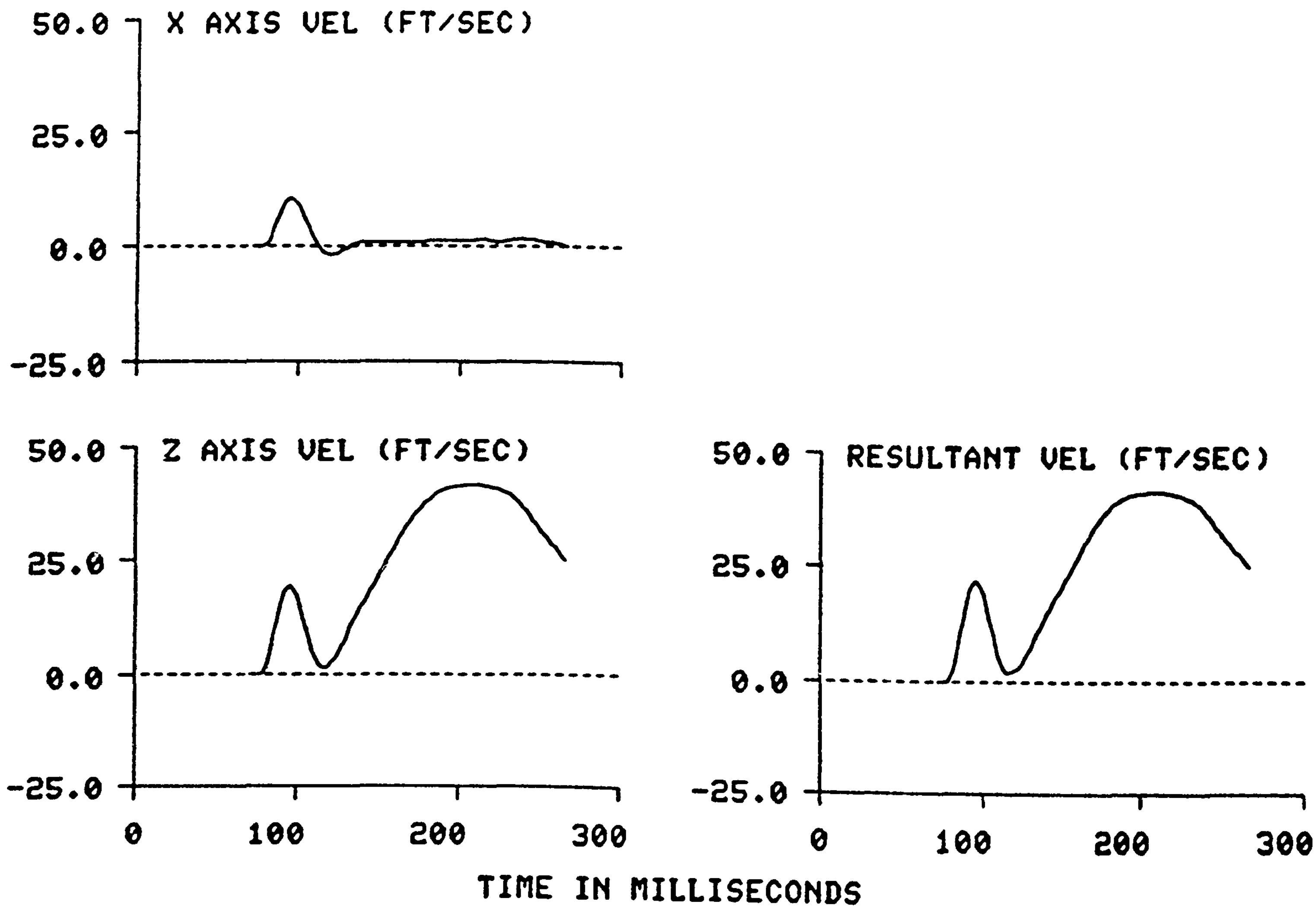

ACES II CATAPULT STUDY TEST: 2102 DATE: 20-NOV-87
FIDUCIAL: CAT EXT2
X AXIS VEL (FT/SEC)
Z AXIS VEL (FT/SEC)
RESULTANT VEL (FT/SEC)
50.0
25.0
0.0
-25.0
0
100
200
300
TIME IN MILLISECONDS

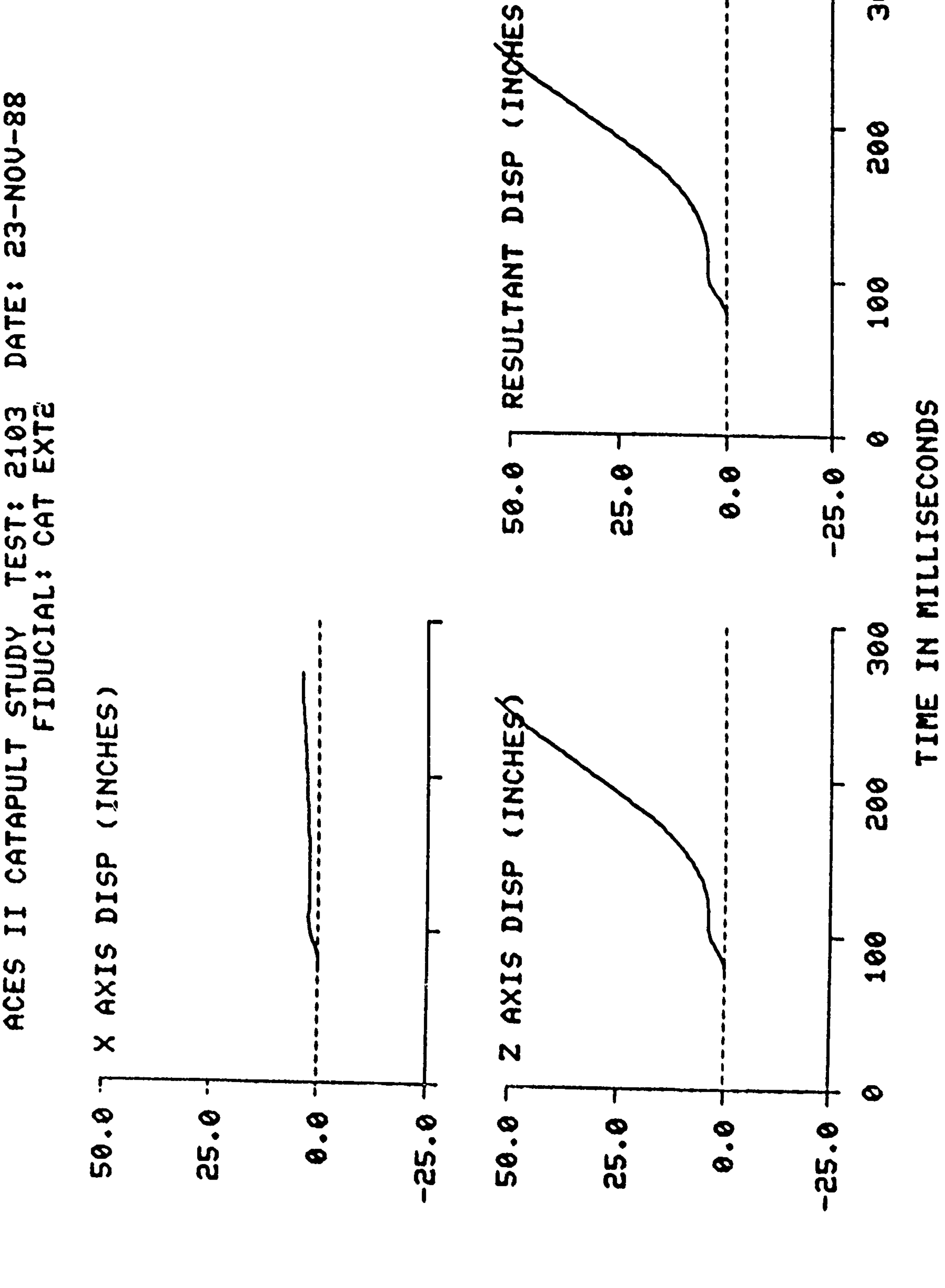
ACES II CATAPULT STUDY TEST: 2103 DATE: 23-NOV-88
FIDUCIAL: CAT EXT1



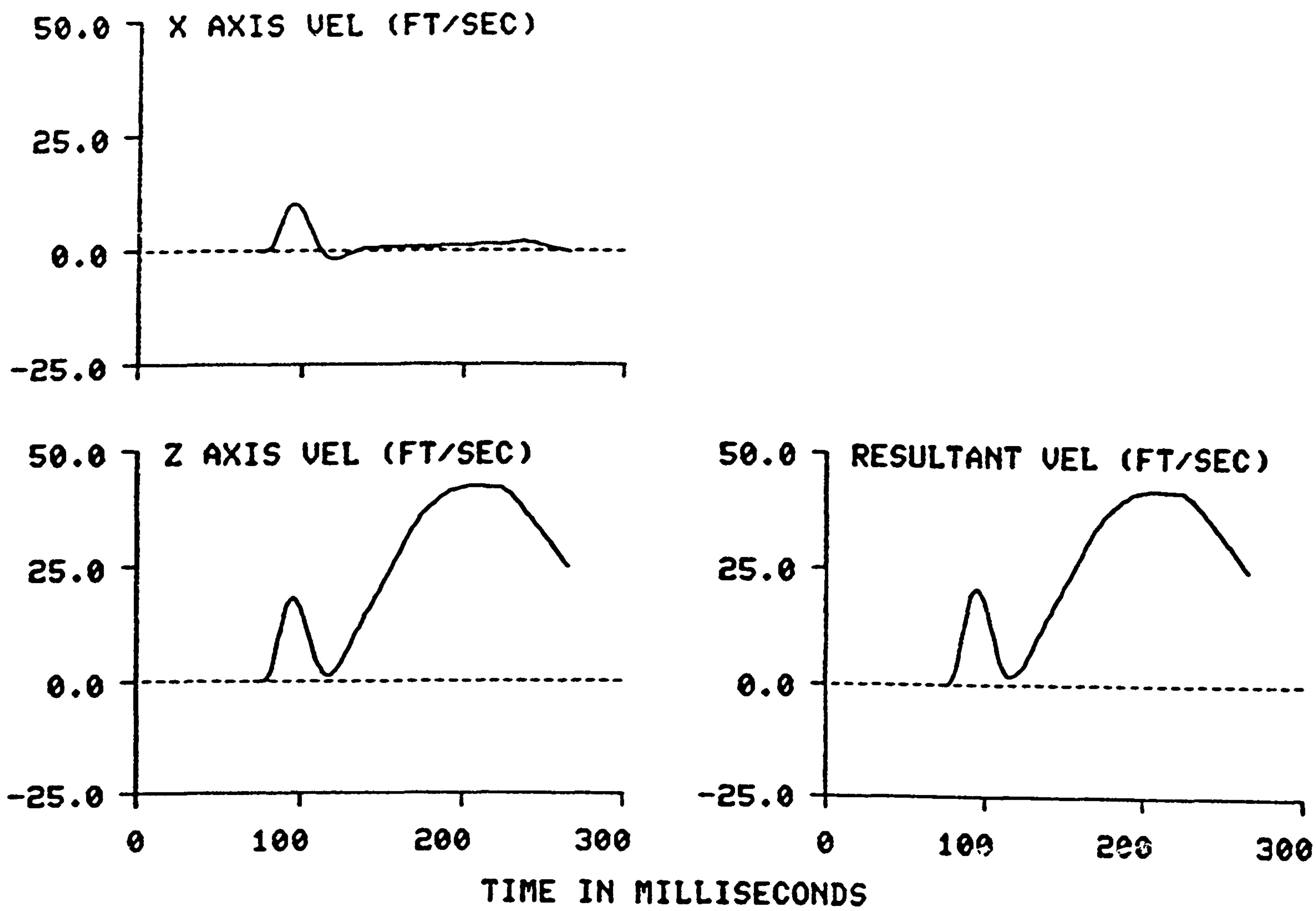
TIME IN MILLISECONDS

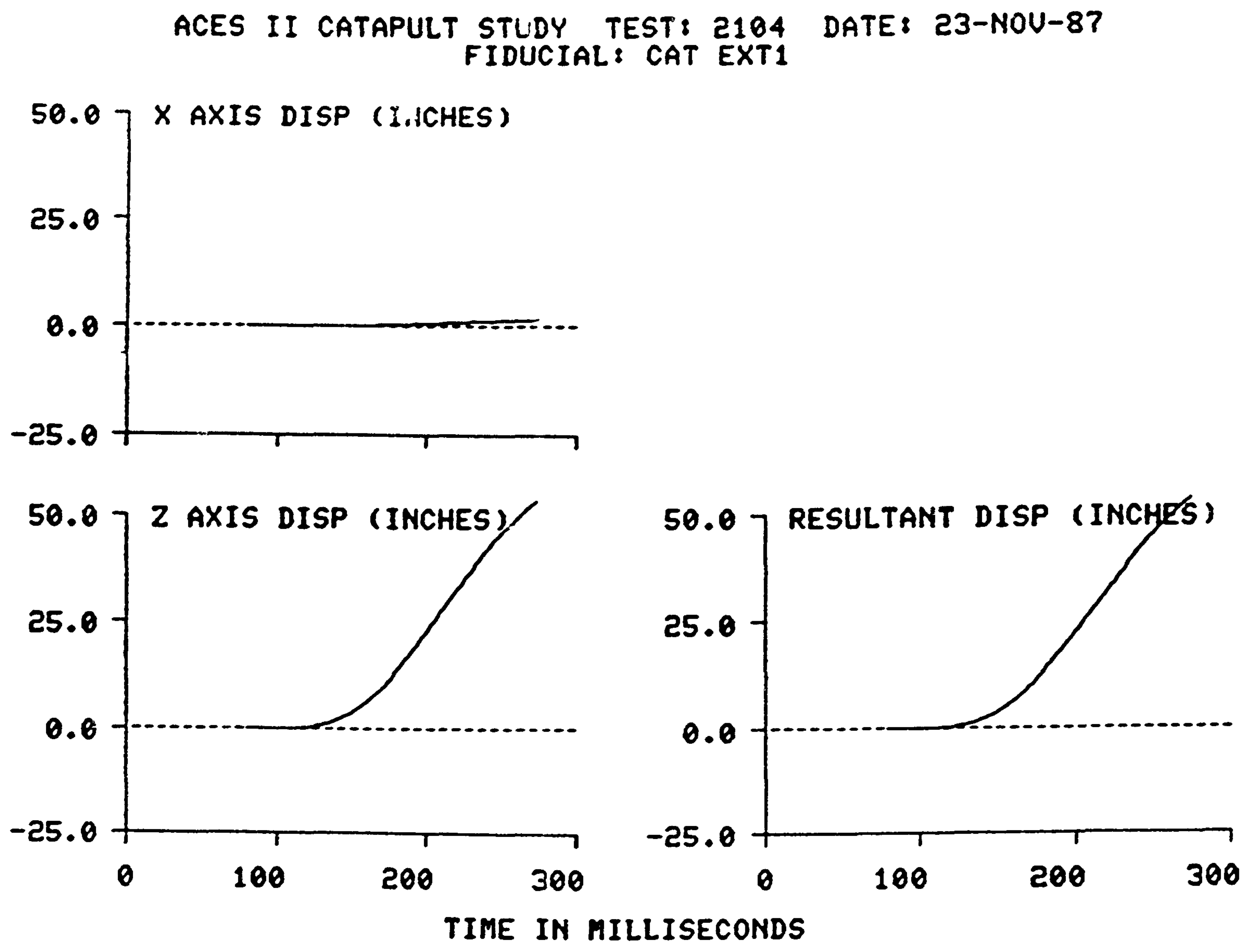
ACES II CATAPULT STUDY TEST: 2103 DATE: 23-NOV-88
FIDUCIAL: CAT EXT1



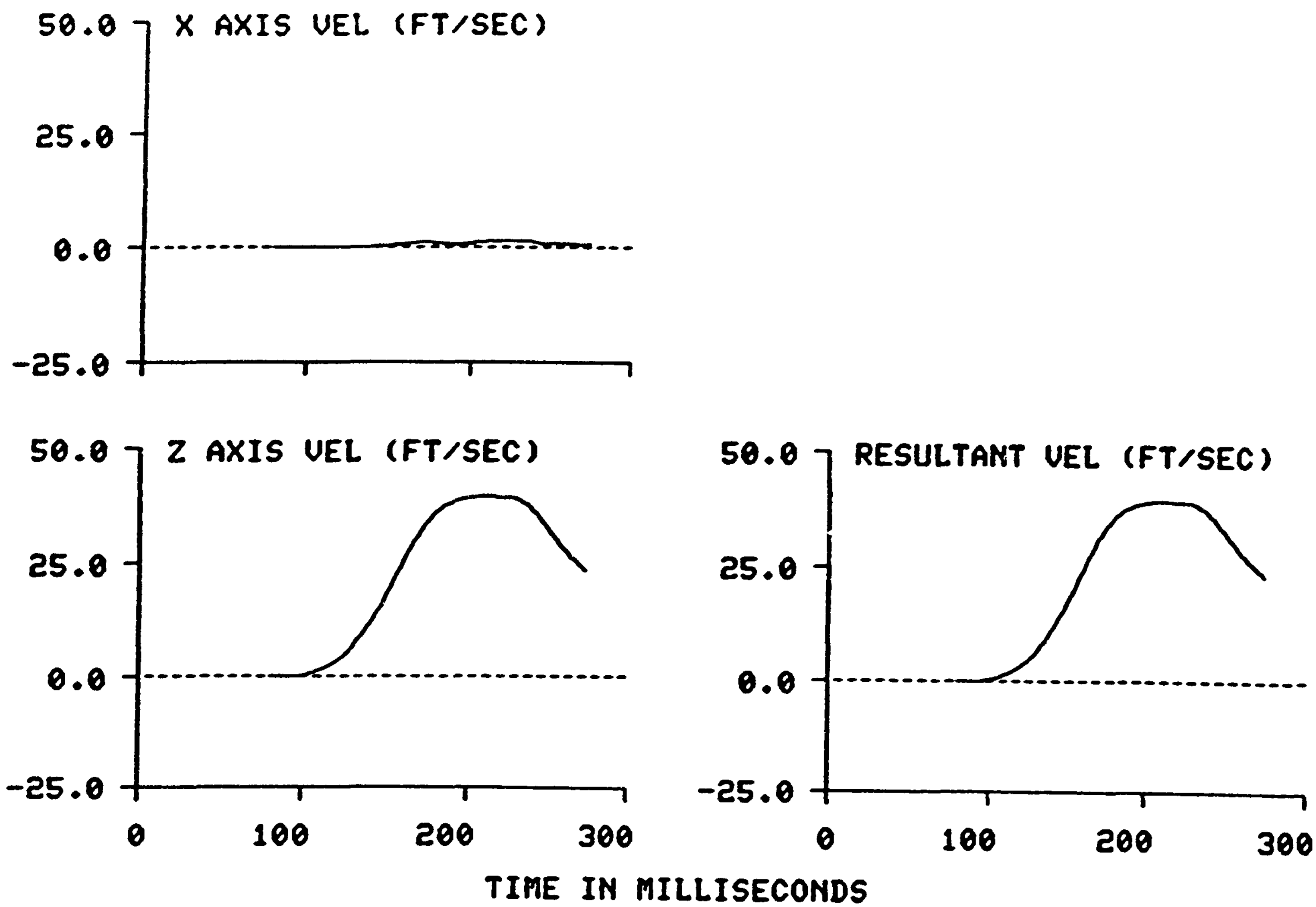

ACES II CATAPULT STUDY TEST: 2103 DATE: 23-NOV-88
FIDUCIAL: CAT EXT2
X AXIS DISP (INCHES)
Z AXIS DISP (INCHES)
RESULTANT DISP (INCHES)
50.0
25.0
0.0
-25.0
0
100
200
300
TIME IN MILLISECONDS

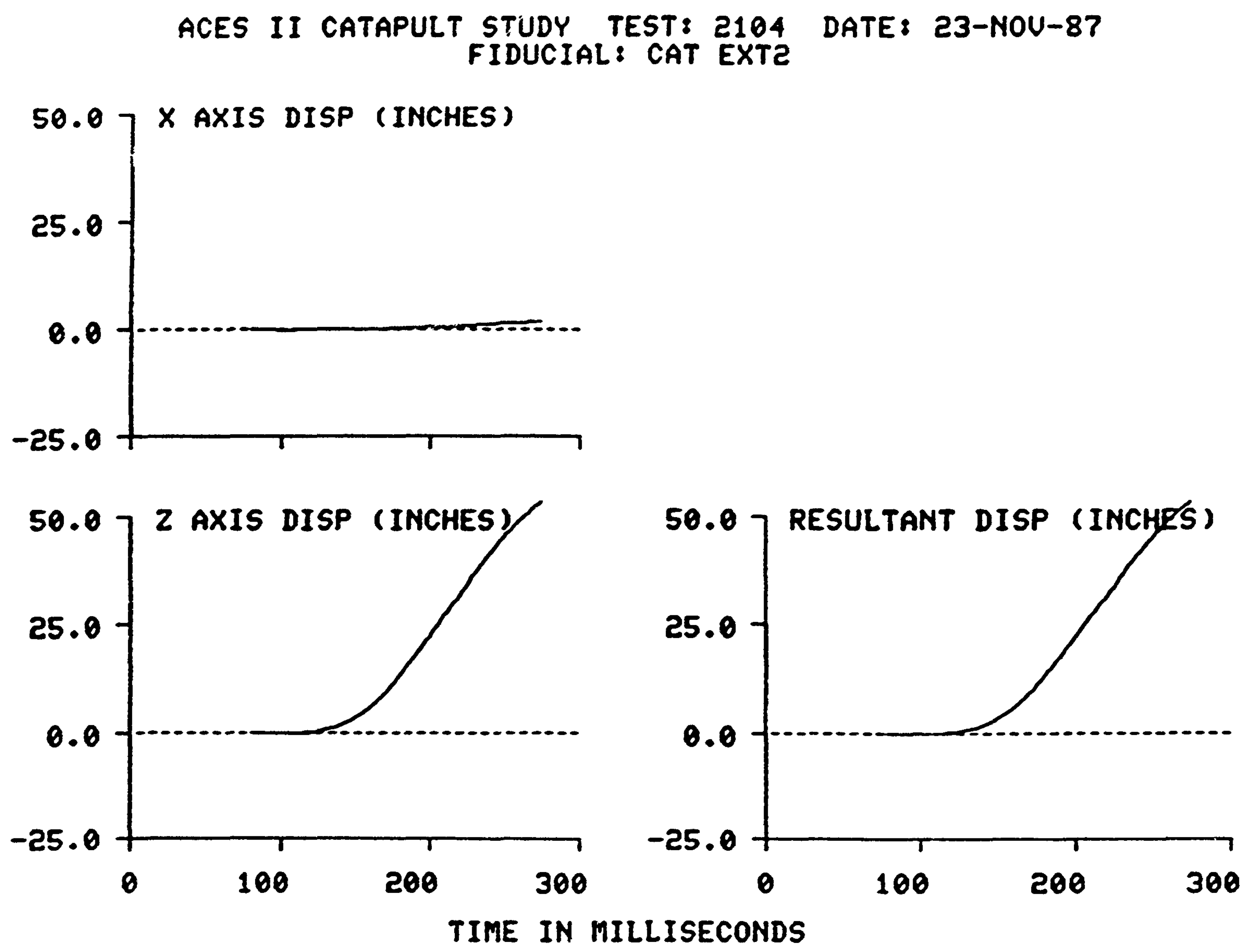
ACES II CATAPULT STUDY TEST: 2103 DATE: 23-NOV-88
FIDUCIAL: CAT EXT2

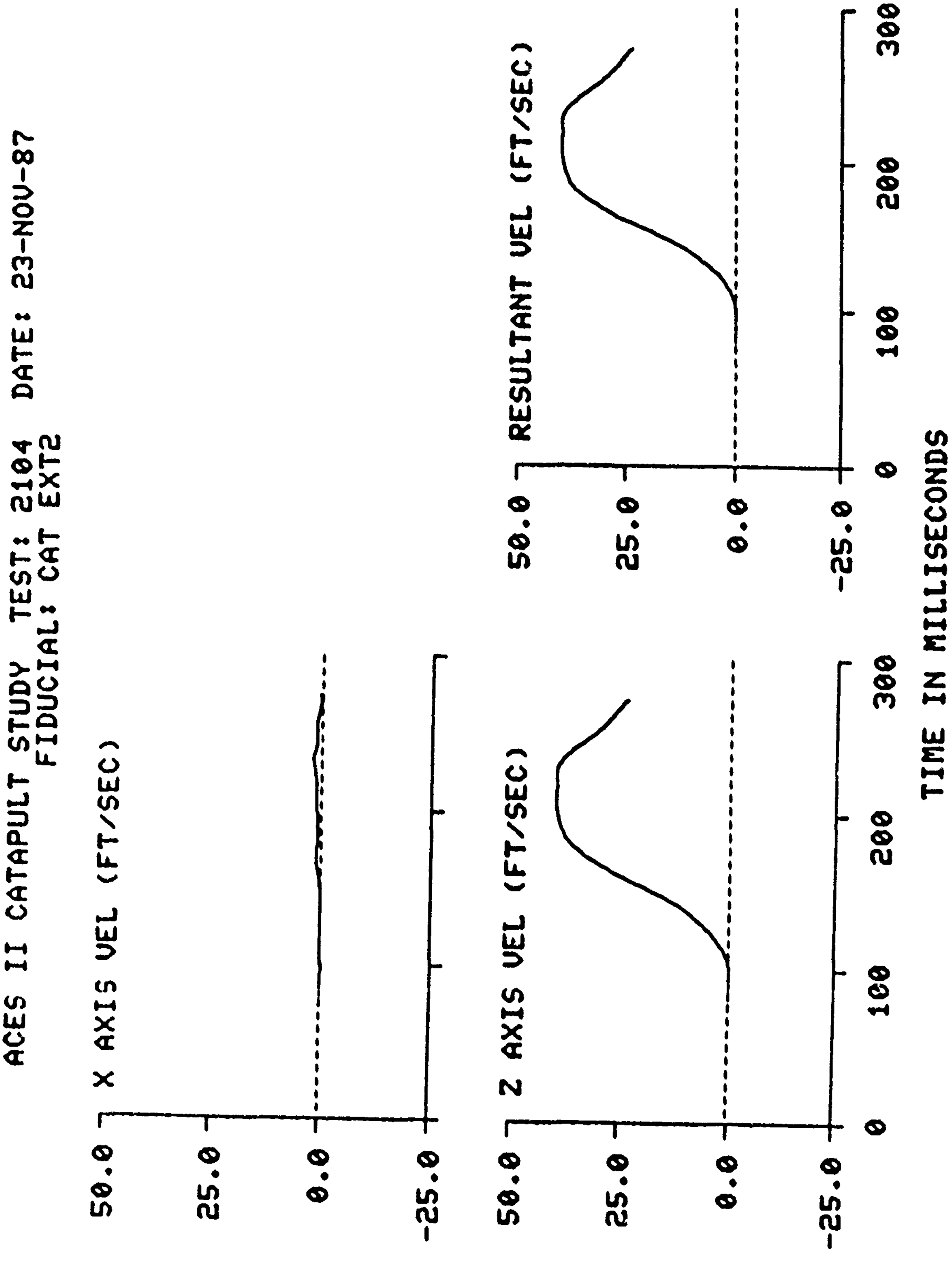



ACES II CATAPULT STUDY TEST: 2104 DATE: 23-NOV-87
FIDUCIAL: CAT EXT1
X AXIS DISP (INCHES)
Z AXIS DISP (INCHES)
RESULTANT DISP (INCHES)
50.0
25.0
0.0
-25.0
0
100
200
300
TIME IN MILLISECONDS

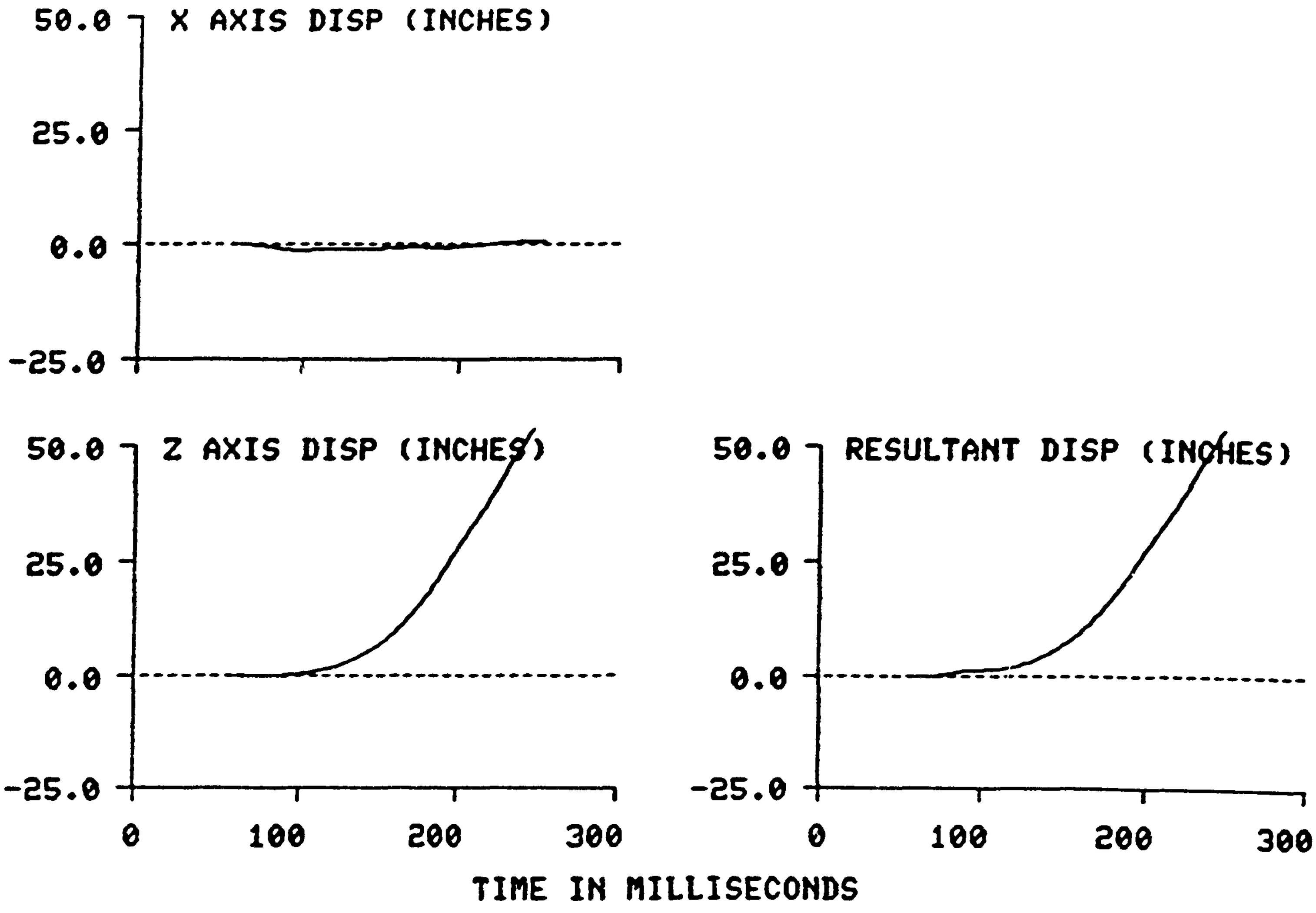
ACES II CATAPULT STUDY TEST: 2104 DATE: 23-NOV-87
FIDUCIAL: CAT EXT1



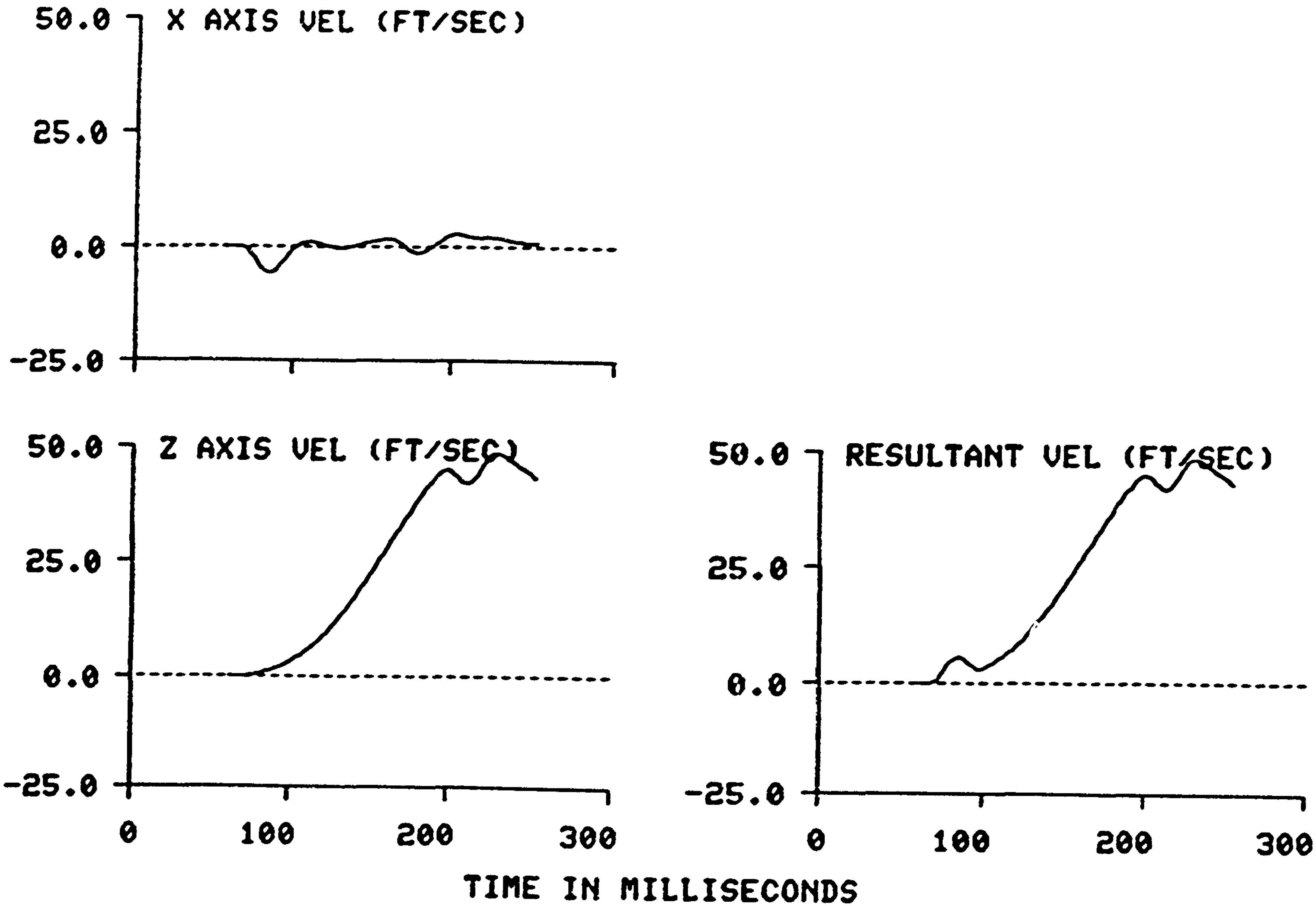

ACES II CATAPULT STUDY TEST: 2104 DATE: 23-NOV-87
FIDUCIAL: CAT EXT2
X AXIS DISP (INCHES)
Z AXIS DISP (INCHES)
RESULTANT DISP (INCHES)
50.0
25.0
0.0
-25.0
0
100
200
300
TIME IN MILLISECONDS

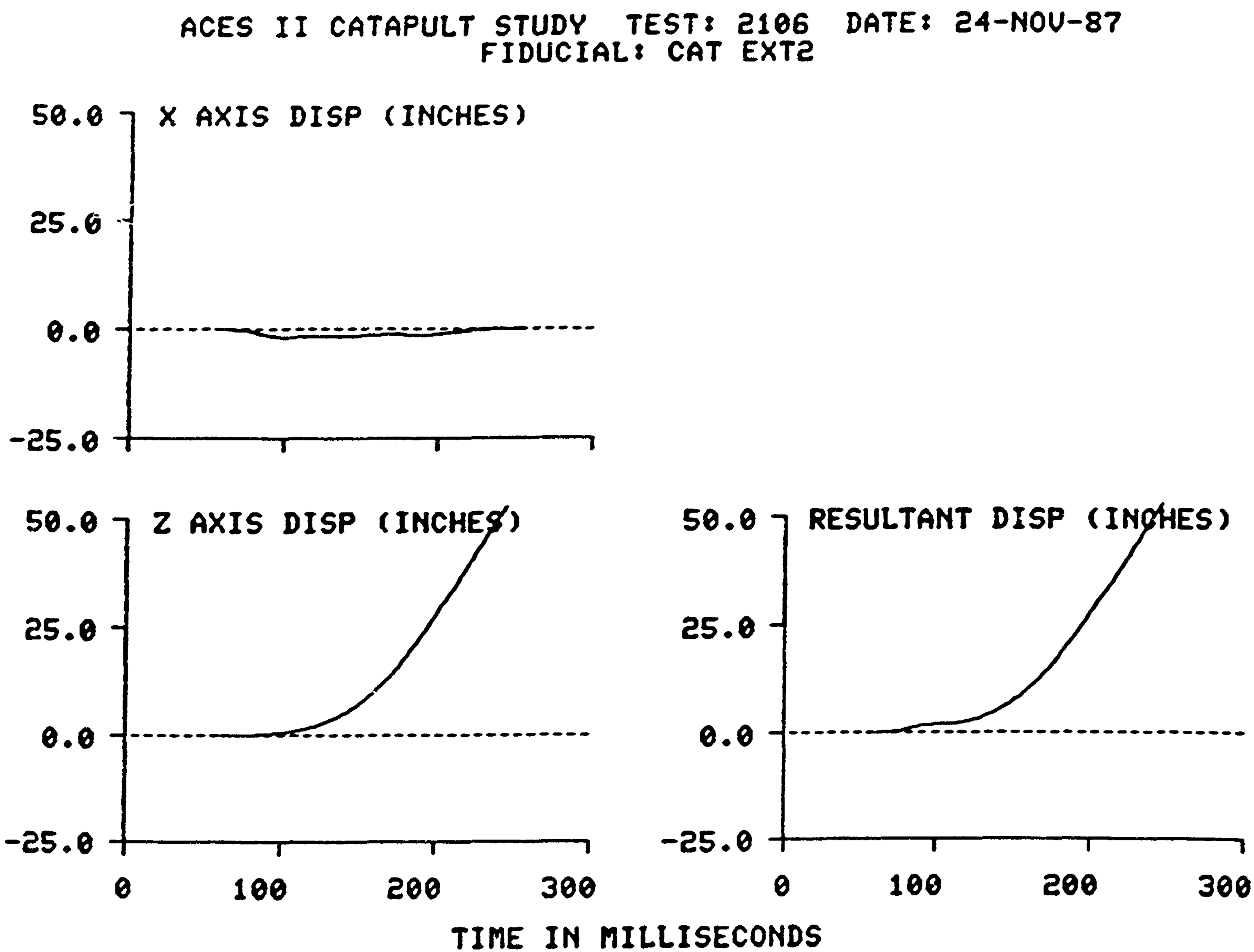

ACES II CATAPULT STUDY TEST: 2104 DATE: 23-NOV-87
FIDUCIAL: CAT EXT2
X AXIS VEL (FT/SEC)
Z AXIS VEL (FT/SEC)
RESULTANT VEL (FT/SEC)
50.0
25.0
0.0
-25.0
0
100
200
300
TIME IN MILLISECONDS

ACES II CATAPULT STUDY TEST: 2106 DATE: 24-NOV-87
FIDUCIAL: CAT EXT1

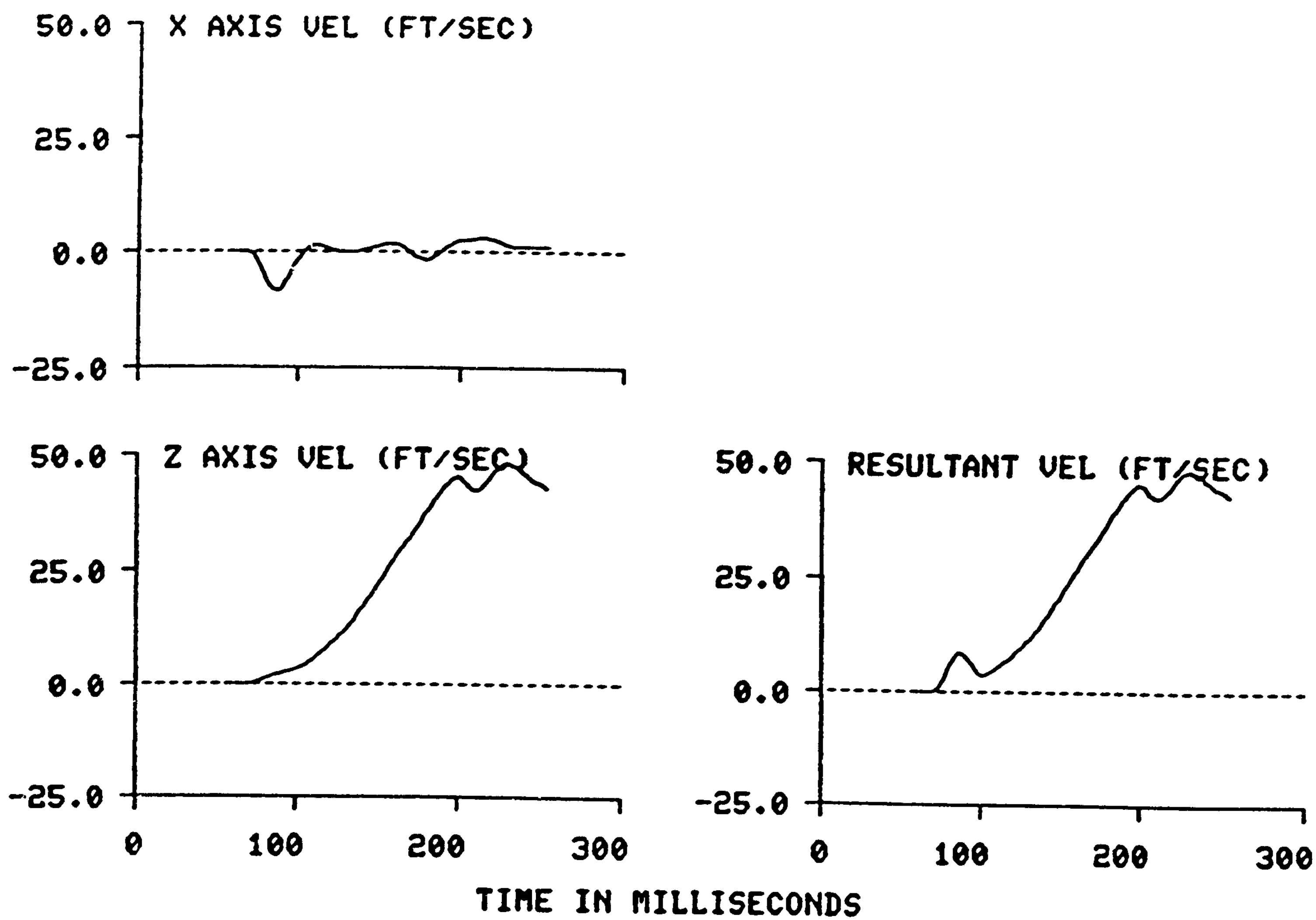


ACES II CATAPULT STUDY TEST: 2106 DATE: 24-NOV-87
FIDUCIAL: CAT EXT1




ACES II CATAPULT STUDY TEST: 2106 DATE: 24-NOV-87
FIDUCIAL: CAT EXT2
X AXIS DISP (INCHES)
Z AXIS DISP (INCHES)
RESULTANT DISP (INCHES)
50.0
25.0
0.0
-25.0
0
100
200
300
TIME IN MILLISECONDS

ACES II CATAPULT STUDY TEST: 2106 DATE: 24-NOV-87
FIDUCIAL: CAT EXT2



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